■ THE TRANSISTOR TURNS FIFTY ■ WHAT BUSINESS CAN LEARN FROM THE RAINFOREST ■

MIT'S
TECHNOLOGY REVIEW

Will it keep the doctor away?



FOOD IRRADIATION

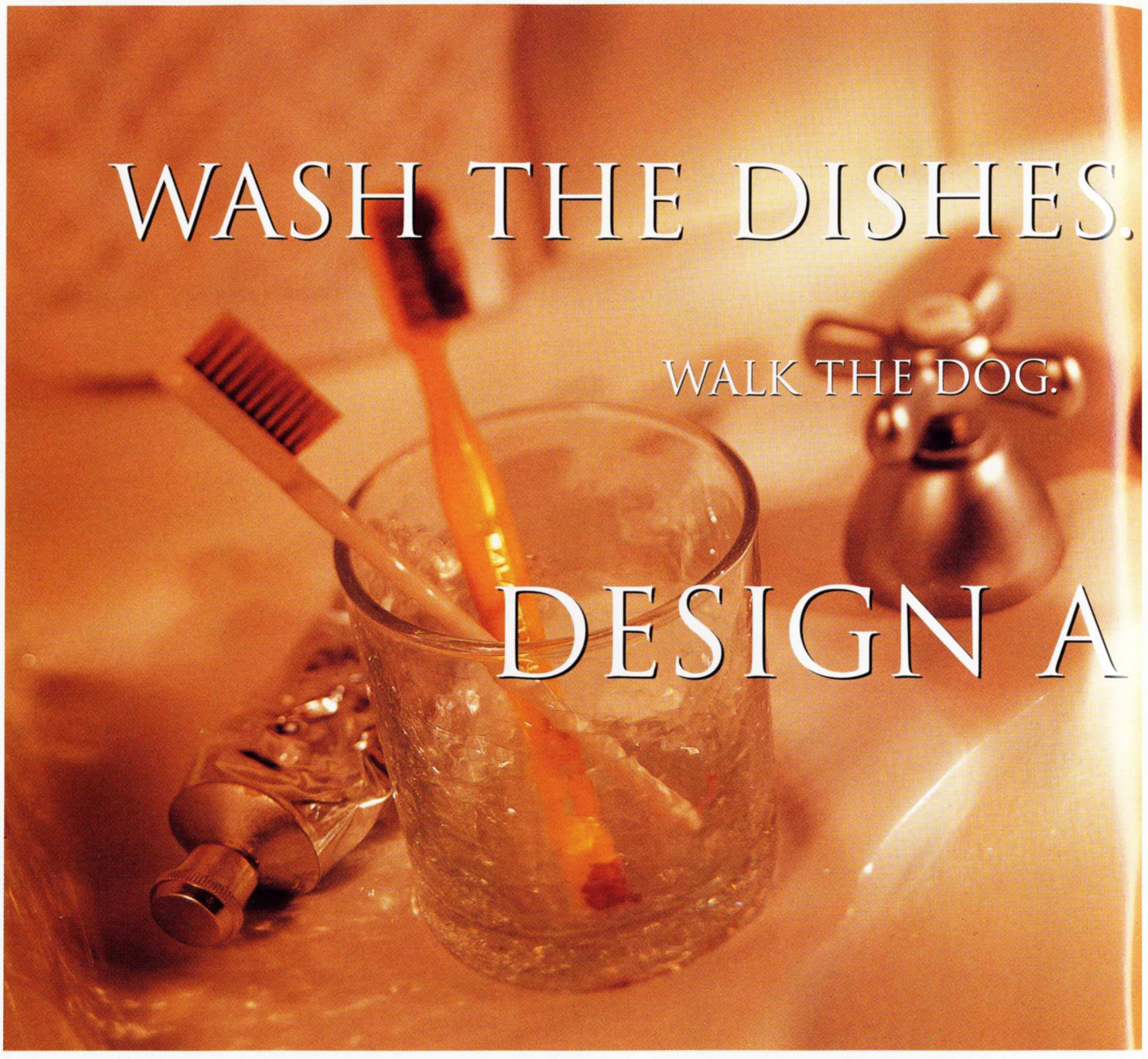
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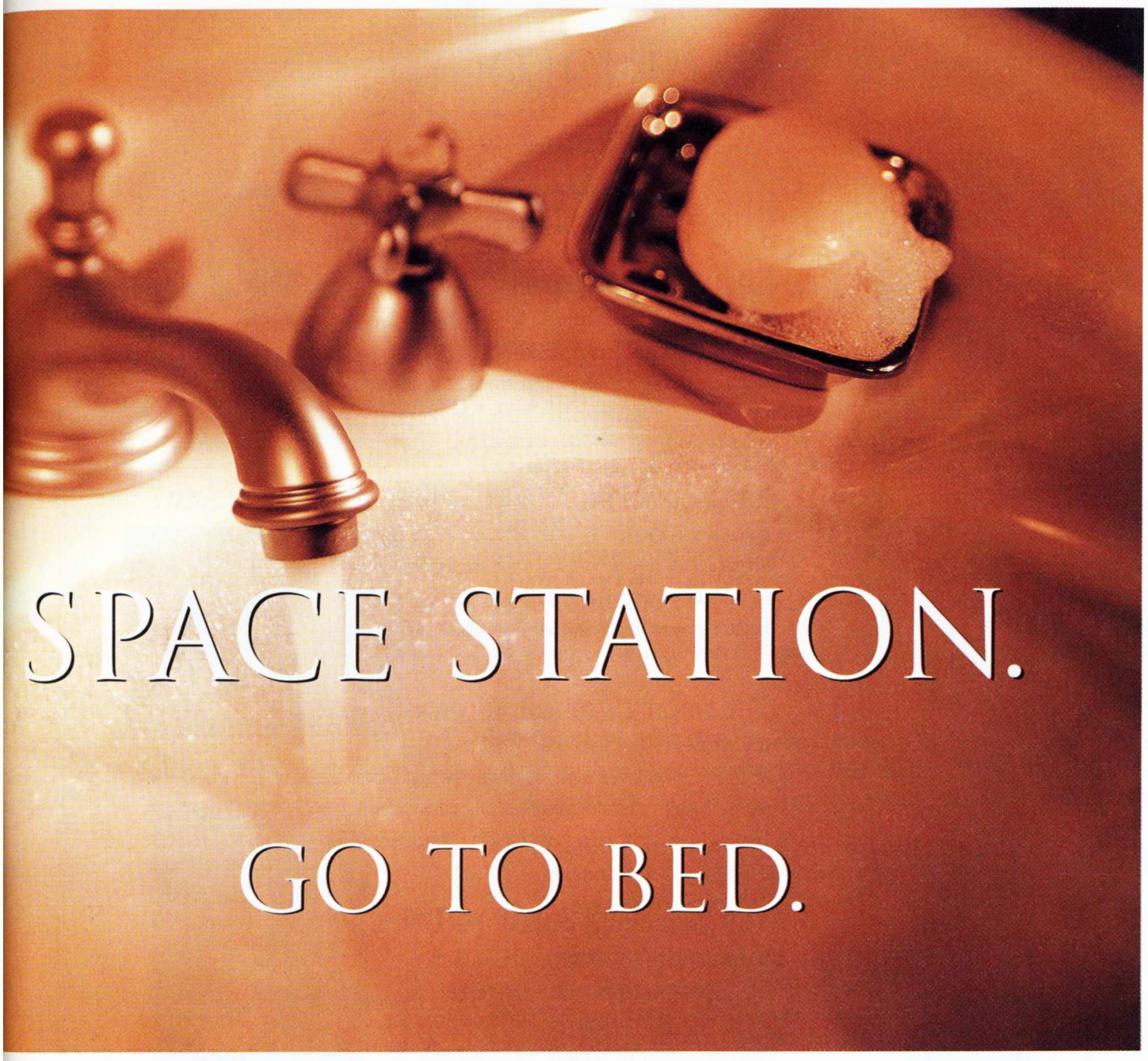


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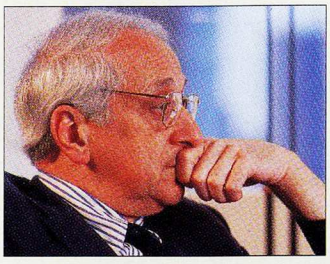


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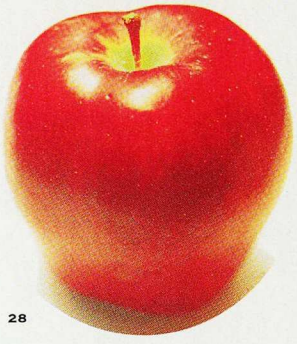
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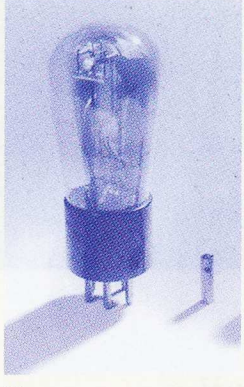
BY P.J. SKERRETT

Irradiation has been approved as a safe and foolproof way to keep disease-causing microbes from creeping into our food supply. But potential public fear of the technology and its high cost of implementation are making food producers avoid it like the plague.

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BY ROBERT HAZEN

In July, we asked readers to tell us whether they agreed with the list of today's most compelling scientific questions compiled by the author, a physical scientist, and biologist Maxine Singer. Many responded with some thought-provoking questions of their own.



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BY MICHAEL RIORDAN

Fifty years ago this month, researchers at Bell Labs put a new theory into practice and set the electronics revolution in motion. The author comments on how the interplay between the practical and the scientific that underlay this development occurs all too rarely today.

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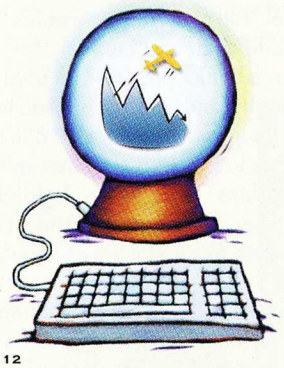
The ancient leatherback sea turtle, one of the world's most endangered species, is also among the most elusive, disappearing for virtually all its adult life into the open seas. To better understand the behavior of these enigmatic creatures and thus develop strategies for protecting them, researchers are turning to tracking and biotech tools.



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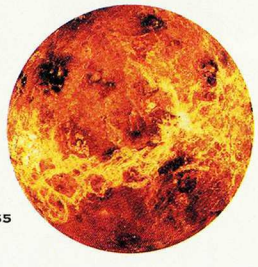
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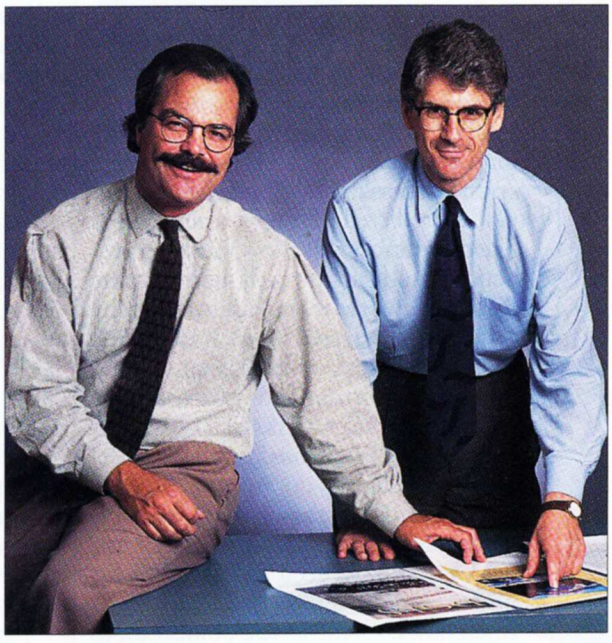
First Line

WELCOMING OUR NEW EDITOR

WHAT could be better than coming to MIT to lead its century-old magazine, which happens to have the word "technology" in the title, into the twenty-first century? We were offering a career-defining opportunity to the right person. We found him in John Benditt.

Last April when we set out to hire a new editor-in-chief for *MIT's Technology Review*, we were at a pivotal point in our 98-year history. For our selection we set the bar very high. The person we chose had to be a highly respected and experienced journalist, who has an MIT level of intelligence, fine editing skills, access to the best science and technology writers in the world, a deep understanding of all aspects of technology, and the capacity to manage and lead a staff of sophisticated writers, editors, and graphic designers. Not an easy person to find.

We were in contact with more than 80 candidates, representing some of the most respected media organizations in the country. Our standards were high and the interviewing process rigorous. As the process led us to several highly appealing candidates, we asked for a detailed vision of what *MIT's Technology Review* would be under their leadership as editor-in-chief. We took the "blank slate approach" with the following conditions: the magazine must be consistent with MIT's purpose, intellectually rigorous, and highly credible. Beyond that we were looking for a clear, focused, and exciting vision that would carry us successfully into our second century and the third millennium.



Partners: Journey and Benditt

I am very pleased to welcome our new editor-in-chief, John Benditt. John met and exceeded our criteria in every way. He was our unanimous choice. His clarity of vision and editorial focus captured the attention of the editorial search committee like no other.

John is a very smart, focused, disciplined professional with a bold and dynamic editorial vision for *MIT's Technology Review*. Over the next several issues, we will tell you more about the unique and exciting plans we have for the magazine. But now let me tell you about John.

The talk around his family's dinner table in Seattle was science (his father was a renowned biomedical researcher) and books (his mother is an accomplished writer). After attending Swarthmore, his career in journalism began with stints at the Seattle *Post Intelligencer* and the Philadelphia *Evening Bulletin*. He did graduate work at the University of Pennsylvania and the University of Washington.

In 1981 he joined the staff of *Scientific American*. Nine years later, he moved to the American Association for the Advancement of Science (AAAS) where he was responsible for bringing a whole new set of freelance writers to *Science* magazine. As features editor, he presided over many of *Science*'s most successful special issues. When we contacted John, he was editor of *Science's Next Wave*, the AAAS's first web-only publication, aimed at improved career options for young scientists. This was a project he had conceived, raised funds for, and founded, also very MIT-like.

With John as our clear choice, he agreed to start at *MIT's Technology Review* on September 15, 1997. My confidence that we had made the right choice was confirmed when John showed up not on September 15, but on September 8—one week early for work. Now, that's what I call a partner!

— *R. Bruce Journey*

An Appreciation

To review the many fine candidates for editor-in-chief we established a search committee made up of remarkable people, ably chaired by Leslie Hruby, senior vice president of The Technology Marketing Group. Her advice and discipline in the process were invaluable in helping us find our new editor and getting him on board on schedule.

The committee included Victor McElheny, director of the Knight Science Journalism Fellowship Program at MIT (a prolific source of candidates, including John) and Ed Thompson, former editor of Reader's Digest, *whose wise counsel was invaluable. Also on the committee were Professor Alan Lightman, head of the Program in Writing and Humanistic Studies at MIT; Bob Metcalfe, inventor of Ethernet and founder of 3COM; Bill Hecht, executive vice president of MIT and CEO of the Alumni/ae Association of MIT; and Genevieve Hammond from Human Resources. All of us at MIT and* MIT's Technology Review *owe them our gratitude for their time and wisdom.—R.B.J.*

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Letters

RETAILERS ON THE INTERNET

Mark Hodges's "Is Web Business Good Business?" (*TR August/September 1997*) does more than discuss Internet commerce in its embryonic stages—it affirms the role of intermediaries, also known as retailers or middlemen, in the online marketplace.

In his book *The Road Ahead*, Bill Gates predicted that new technologies like the Internet will allow market transactions to occur directly between the customer and the manufacturer, thereby eliminating the need for intermediaries. But the Internet businesses that Hodges highlights (Virtual Vineyards, a wine store; Cyberian Outpost, a computer retailer; and Amazon.com, a bookseller) are intermediaries, not manufacturers.

The question of the intermediaries' survival is being hotly debated. The businesses that have been successful so far understand the Internet and harness its capabilities. As the article points out, to gain market share, these businesses are working to retain their customers early on by offering greater product selection and shopping convenience. As customer-intermediary relationships develop, trust and familiarity increase the potential for future market transactions.

What does the future hold? Perhaps Gates and others may be right in predicting that personal Internet agents and search engines can manage commerce. However, I suggest that intermediaries will be necessary for Internet commerce to survive. Without Amazon.com or Virtual Vineyards, how could we approach the overabundance of consumer choice on the Internet to ensure that we found the best product at the best price?

JOSEPH P. BAILEY
PhD Candidate
Technology, Management,
and Policy Program
MIT

With book buying as an example, Langdon Winner promotes his thesis in "The Neverhood of Internet Commerce" (*TR August/September 1997*) that online businesses will destroy local neighborhoods and human interaction. I happen to love buying books from Amazon.com, the specific Internet vendor Winner mentions. The battle is not between



Internet commerce and neighborhood businesses, as Langdon portrays. It is between service from imaginative, customer-oriented businesses and the lack of service at chain bookstores.

If my local bookstore doesn't carry the book I want, its ability to order and deliver it to my home is nonexistent. Amazon.com also provides other services that guide my shopping, such as postings of reviews and "links" between books I know and those I don't. Only a lack of imagination and enterprise has stopped offline booksellers from offering such services—and earning my business.

RONALD S. NEWBOWER
Acton, Mass.

Winner's analysis of Internet shopping does not consider its enormous social benefits. As Hodges pointed out, successful Web-based retailers, such as Amazon.com, provide their customers with ways to exchange their opinions on books with one another, thereby improving the shopping experience. Retailers who leverage the Internet's ability to provide such services are creating communities of like-minded consumers

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that otherwise may not exist offline.

Winner, who mentions that his son likes books by Brian Jacques, may be interested in online communities such as the official Brian Jacques site and the rec.arts.books. childrens discussion group.

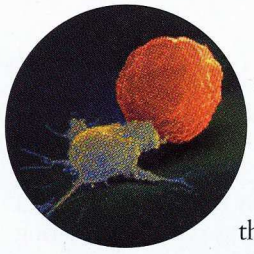
JASON REYES
Sharon, Mass.

CANCER THERAPY QUESTIONS

The need to develop more effective and less toxic therapeutic approaches to cancer, such as the immunotherapy discussed by Ronald M. Kline and Sunil Chada in "Killing the Last Cancer Cell" (*TR May/June 1997*), is urgent. Cancer is still the principal cause of death by disease in children, and will likely soon surpass cardiovascular disease as the number one cause of death. The primary reasons why patients with cancer are not cured continue to include the resistance of tumor cells to chemotherapy and the illness and death associated with treatment.

While approaches that stimulate the immune system are incredibly appealing, however, many substantial obstacles remain. Techniques for transferring stimulating agents into tumor cells are nascent. What's more, which ones are best is far from clear; researchers are just now trying some combinations in animals. Little is known about the best timing for such treatments when used with chemotherapy and the transplantation of stem cells, the bone-marrow cells that produce other blood cells. (For example, patients with blood-related cancers, such as leukemia, may have their blood and stem cells replaced with clean stem cells with the hope that cancer-free blood cells will be generated.) Major questions also exist about unwanted effects of potential toxicities of such approaches, including autoimmune responses and lower immunity to other infections.

Hockey great Wayne Gretzsky has reportedly said, "The difference between me and other players is they go where the puck is and I go where the puck is going to be." Many investigators are hopeful that modulation and redirection of the immune system will



be where the next important cancer therapies will emerge. While pursuing this goal, it will be essential to execute carefully designed trials so that future treatments will be based on a firm foundation.

ROBERT J. ARCECI
Professor of Pediatrics
Director of Hematology/Oncology
Children's Hospital Medical Center
Cincinnati, Ohio

SHEDDING LIGHT ON ECLIPSES

"When the Sun Disappears and Dolphins Do Back Flips" (*TR April 1997*) by Steve Mirsky is well written. "Eclipses and Einstein," which accompanies the article, misrepresents Einstein's theory of relativity, however. Mirsky writes, "The theory says that light energy, being equivalent to matter, will be attracted by masses." This is a Newtonian interpretation of the bending of light. If relativity were false, the light would still bend, albeit half as far, for the reasons stated. But a fully relativistic statement should recognize that light follows the curved space-time in the vicinity of the sun and thus bends twice as far as the Newtonian prediction. In other words, the bending of starlight alone would not have proved Einistein's ideas; the measured size of the angle—1.75 arc seconds—did.

NEIL D. TYSON
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Mirsky's account of a recent voyage to witness an eclipse of the sun revived pleasant memories of similar experiences my family and I had in 1972 and 1973. I heartily endorse his recommendation to observe such an eclipse, an awe-inspiring event that defies description. The company aboard such expeditions is also wonderful—amateur astronomers are an interestingly varied lot.

PHIL LONG
Saint Louis, Mo.

THE FUTURE OF MEMORIES

In "From Here to Eternity" (*TR April 1997*), Samuel C. Florman muses that if he immediately started digitizing his photos and movies, he might be able to pass them onto his great-grandchildren. However, he worries that digitization's ability to survive into infinity might cause future generations to drown in trivia. Future generations? We are drowning in trivia right now. Which image-file format should we save our photos in? With what software? From which operating system and platform?

As technology advances, new methods will be created to convert files to new formats. However, I wonder how many people will actually take the time to save their photos and movies in the latest formats. For example, I know of very few people who have converted their 8-mm home movies to VHS. Even though I work with computers every day, I can hardly keep up with upgrades and new software for my professional use, let alone my personal pleasure. Information's survival will not depend on the durability of its physical medium. Rather, it will depend on the amount of energy people put into keeping information readily accessible.

BRIAN SHULTZ
Menasha, Wis.

CAR TALK

Jane Holtz Kay's provocative essay "Without a Car in the World" (*TR July 1997*) shows what one determined citizen can do to turn the tide against the car-centered American culture. That is no easy task. The United States is home to half the world's cars and has more cars than licensed drivers. Suburbanites ask themselves whether they should buy an immense sport-utility vehicle—not because they have taken up ranching, but because they no longer consider a mere car to be safe on highways overrun by such vehicles.

Our massively subsidized infrastructure makes driving individually efficient. But this is not so at the social level. The environmental and cultural impacts of a car-based transportation system are depressingly long term and severe. Cars demand land, and they promote living habits that require ever-increasing amounts of it. They present major safety dilemmas. For example, cars are the number-one killer of children in the United States. Their dominance blocks alternatives such as public transit, bicycling, and walking. And they reinforce a rugged individualism that is poorly suited to the demands of an interdependent polity.



What can be done? Cutting car subsidies and raising gas prices so they internalize the social and environmental costs of driving would be an effective beginning, but those measures are considered political non-starters. Electric and advanced-hybrid vehicles and alternative fuels may also help, but neither addresses driving's demand for land.

The effort to restore sustainability to transportation must begin at home. The Conservation Law Foundation and other transportation-reform advocates are working directly with communities that have first-hand knowledge of the shortcomings of a transportation system that is out of balance. Together we are pursuing solutions that include better bicycle and pedestrian facilities, rehabilitation of older industrial sites in urban areas into places of commerce and employment, urban infrastructure improvements and traffic calming (new traffic engineering and design features that will slow cars down and make the

Continued on page 68

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TRAIN SAFETY

Detecting "Rail Cancer"

The progressive growth of hidden cracks within railroad tracks, known as "rail cancer," is a major safety hazard in the railroad industry. Crosswise cracks that begin with tiny flaws inside the steel rails can grow into surface cracks and eventually cause the rails to break. In the effort to prevent derailments, service cars equipped with special sensors travel the nation's railroads, seeking out signs of rail cancer and other defects. But because the sensors require direct contact with the rails, the cars have to creep along at speeds averaging less than 15 miles per hour, forcing commercial train traffic in the area to shut down.

Finding a more efficient, cost-effective method of track maintenance and inspection is a high priority for the railroad industry, according to Jim Lundgren, head of the American Association of Railroads' (AAR) Technology Scanning Program for identifying and addressing critical areas of railroad-related research. "We need the ability to do more frequent and thorough inspections that do not interfere with revenue-generating traffic," he says. Now an MIT team led by civil and environmental engineering professor Shi-Chang Wooh is investigating ways of detecting potentially lethal cracks at high speeds while the nation's trains are running.

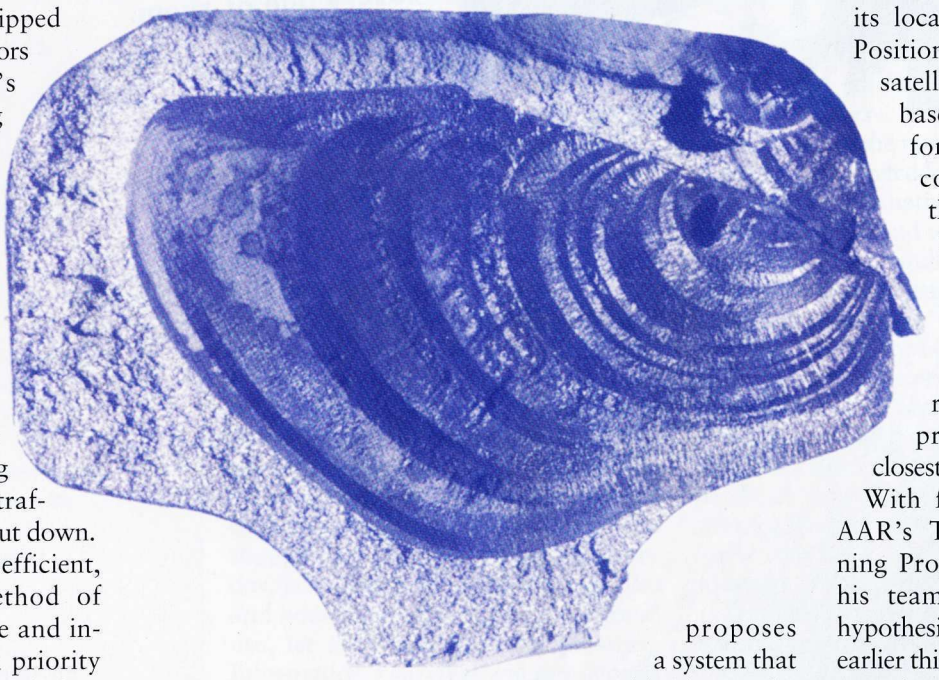
Early rail-defect detection techniques involved passing electric currents through the tracks and looking for changes in direction or drops in voltage that would indicate the presence of a crack. For the last 30 years, however, operators have relied largely on ultrasound, sending an ultrasonic signal directly into the rail and measuring the time it takes to bounce back. A crack prevents the signal from reaching the base of the rail, so it bounces back more quickly.

The goal of Wooh's team is to use ultrasonic detection in a way that does not require contact between the sensors and the tracks. An expert in ultrasonics and materials evaluation, Wooh proposes a system that would rely on the Doppler effect—the shift in the frequency of sound waves that occurs as a moving object, such as a whistling train or wailing ambulance, approaches and then recedes from a stationary object. As the distance between the two objects narrows, the sound waves pile up and the frequency and pitch become higher; when the distance increases, the waves spread out again and the frequency and pitch become lower.

Similarly, a high-speed monitoring system that continuously directs an ultrasonic beam downward at the rail as it passes by would register a slight Doppler shift in the frequency of the response signal over a defect, such as a surface crack or rail break, according to Wooh.

Wooh suggests that once a detector identified a problem area, it could broadcast its location to a Global Positioning System (GPS) satellite. A ground-based Graphical Information System could then obtain the area's position from the GPS satellite and provide maintenance personnel with a map showing the range of track with problems and the closest rail service station.

With funding from the AAR's Technology Scanning Program, Wooh and his team tested out this hypothesis in the laboratory earlier this year. "We limited ourselves to [testing for] cracks on the surface," Wooh explains. To simulate the motion of detectors along flawed tracks, the team beamed an acoustical signal from a piezoelectric transducer—a vibrating device that converts electrical power to acoustic power and vice versa—toward the rim of a spinning metal wheel. The rim of the wheel,



Like the rings in a tree stump, the concentric circles shown in this cross-sectional view of a steel rail reveal the progressive growth of fractures inside the rail. Scientists at MIT are now investigating high-speed techniques for detecting these cracks before they reach the surface.

PHOTO: AAR/TTC

which represented a moving rail, was marred by a notch, which represented a crack in the rail. A second transducer picked up the signal after it bounced off the rim, and converted it into digital data. To test different train speeds, the researchers spun the wheel at various rates.

Using software to analyze signal responses collected as the wheel spun, Wooh's team determined that the sound-wave frequency obtained above the notch was higher than that found over the rest of the wheel. According to Wooh, similar detectors mounted on a train running at 60 miles per hour could send and receive ultrasound signals and a signal-processing chip could evaluate the responses immediately.

Finding a more efficient, cost-effective method of track maintenance and inspection is a high priority for the railroad industry.

While this laboratory experiment demonstrated the viability of this approach for detecting surface cracks at high speeds, a much more challenging problem remains: detecting cracks hidden inside the rails before they reach the surface.

The key difficulty in applying the same method to interior cracks is that sound transmitted through air will bounce off the rails but not penetrate them. So Wooh is experimenting with techniques that will generate ultrasound signals from inside the rail rather than from above. The most promising technique, he believes, is laser-based ultrasound. A device mounted on the train will emit a laser beam that creates a warm spot on the track surface. As the warm spot expands against resistant, colder metal, the resulting tension will produce an acoustic stress wave within the track. When the sound waves generated in the rail pass through a transverse interior crack, they will pile up, causing an increase in wave frequency.

Wooh points out that industries from aerospace to piping have used laser-based ultrasound to detect flawed materials. However, these techniques have not been used for high-speed monitoring and have relied on intermittent rather than continuous laser beams, which would provide the most thorough coverage. With limited funding from the AAR, Wooh's team is now designing experiments to test the use of both intermittent

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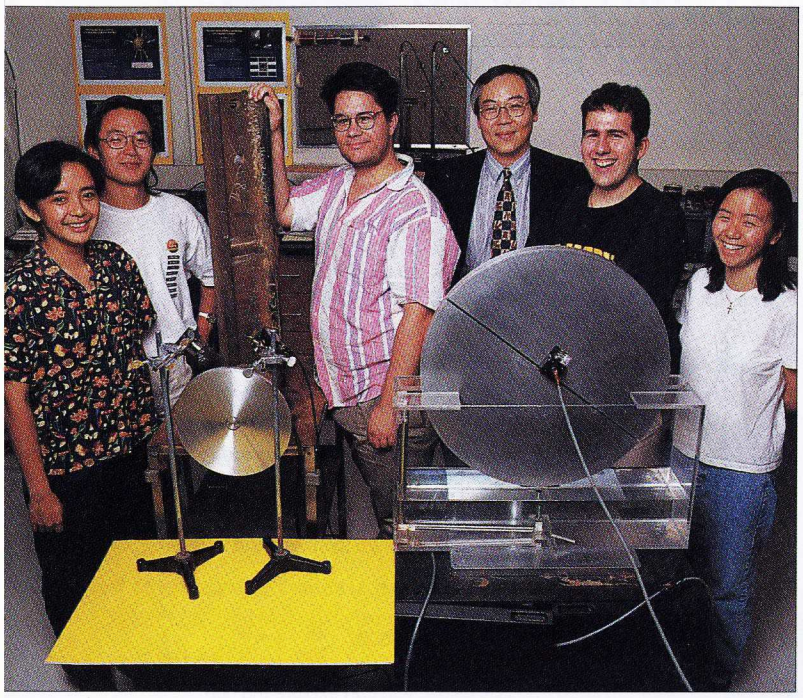
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MIT civil and environmental engineering professor Shi-Chang Wooh (center) and a team of researchers beamed an ultrasound signal at the rim of a spinning wheel to test techniques for high-speed detection of surface cracks in steel rails. Members of the team include (left to right) Karen Veroy, Coach Wei, Art Clay, Lawrence Azar, and Casey Kim.

and continuous laser-based ultrasound to detect and monitor subsurface cracks. According to AAR principal investigator Richard Reiff, if laboratory tests prove successful and Wooh can develop a promising prototype for rail-defect detection, he can test it on the Gauntlet, a stretch of track containing more than 50 defects at the AAR's Transportation Technology Center in Pueblo, Colo.

Wooh argues that the investment in new hardware required for high-speed detection will be more than offset by the cost savings it entails. In an era when freight and passenger railroad traffic is growing, notes Federal Railroad Administration Track Safety Specialist Al MacDowell, "the window to get out on the tracks for inspection is getting smaller and smaller."

— *Mark Dwortzan*

CORPORATE STRATEGY

A Model for Maturing Markets

You are the CEO of a fast-rising technology-based company. You've carved out a niche in your industry with an innovative product that generates a tidy profit. Suddenly new entrants are elbowing their way into your market, threatening to set off a storm of competition and drive prices—and profits—down. What do you do?

Ask Henry Birdseye Weil.

Weil, a senior lecturer in the Strategic and International Management Group of MIT's Sloan School of Management, says the process of "commoditization"—the descent into entrenched price warfare that erodes profit margins and chokes off funding for innovation—is inevitable in any industry. However, he maintains that top managers often fail to perceive options for slowing the spiral. He has created a computer simulation of the commoditization process that can be adapted to any industry.

"My goal," says Weil, "is to understand the forces that drive the life cycle of companies and industries, and to work with individual companies to help them anticipate or contend with these forces."

Commoditization is an "understudied" area, notes William Lukas, executive director of MIT's International Center for Research on the Management of Technology (ICRMOT), which funds Weil's research. So far, Weil has adapted the simulation to model the airline, telecommunications, and oil and chemical industries; he hopes next to turn his attention to mobile telecommunications service providers in Hong Kong, an "adolescent" industry just beginning to grapple with the dynamics of a maturing market.

Weil's project began in 1994 when a group of telecommunications companies affiliated with ICRMOT approved his proposal to create a model of the U.S. airline industry to examine the impact of deregulation. "I felt that there would be strong parallels between what happened in the airline industry and what is happening in the telecommunications industry," Weil explains. "Remember, in the early years of deregulation, airlines were viewed as an exciting growth industry with lots of capital and lots of startups. Fifteen years later, it is widely viewed as a sick industry. We wanted to understand what happened—and to what extent these dynamics might be universal across industries."

The simulation he developed is based on systems dynamics, a computer-modeling method pioneered at MIT in the 1960s by Jay Forrester. The simulation explores feedback relationships among economic and industry variables such as the rate of overall economic expansion, growth in demand, intensity of competition, production capacity, and the pace of technological change.

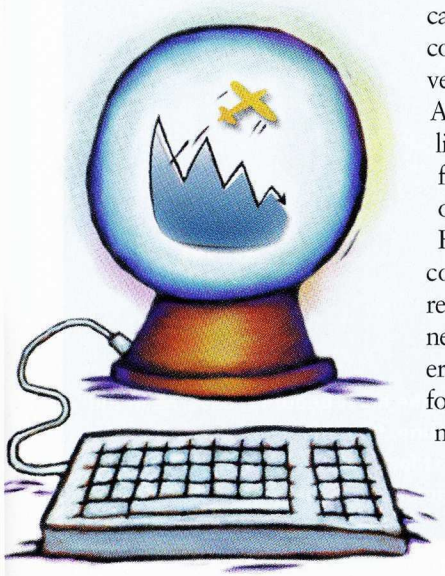
Weil then used the simulation to test alternative business strategies that the airlines

PHOTO: L. BARRY HETHERINGTON

might have pursued. "The airlines could have behaved in a much more intelligent way," he says. The established airlines failed to predict that the new carriers entering the deregulated market would devastate the existing fare structure. By anticipating those price changes and cutting costs sooner, he argues, airlines might have avoided colossal losses.

The airlines also misread the effects of deregulation on market growth. Although slashing fares released a certain amount of pent-up demand, the spurt in market growth wasn't sustainable. As a result of their mistaken reading of the market, the airlines bought more planes than they needed—and then had to cut prices again to fill them.

The airline simulation "helped us see how telecommunications companies in other parts of the world—France, Germany, Latin America, and parts of Asia—could contend with similar dilemmas as they follow the United States into deregulation," Weil says. With the cooperation of ICRMOT member companies France Télécom, Electricité de France, the British Cable and Wireless Group, and its affiliate Hong Kong Telecom, he adapted the simulation to create a model of that industry. His research attracted the interest of two other ICRMOT sponsors, British Petroleum and the chemical firm ICI, which asked Weil to create a model of the petroleum industry last year.



Since then, Weil has used his simulation to identify strategy options for companies facing maturing markets—and his models have generated some counterintuitive solutions. Traditionally, for example, established companies have tried to limit total capacity in an industry by forcing new entrants to duplicate established companies' investments. This strategy is based partly on the belief that, once competitors have entered the field, the need to earn a return on their investment will force them to keep prices high.

"History has shown that that's absolutely incorrect logic," Weil asserts. "Once the capacity is in place, it's a sunk cost and people will compete very aggressively to fill it up." According to his models, established companies may even find it to their advantage to offer capacity to new entrants. For instance, one British telecommunications company recently decided to lease excess network capacity to newcomers to the market rather than force them to build their own networks; the leases have become a substantial new revenue source.

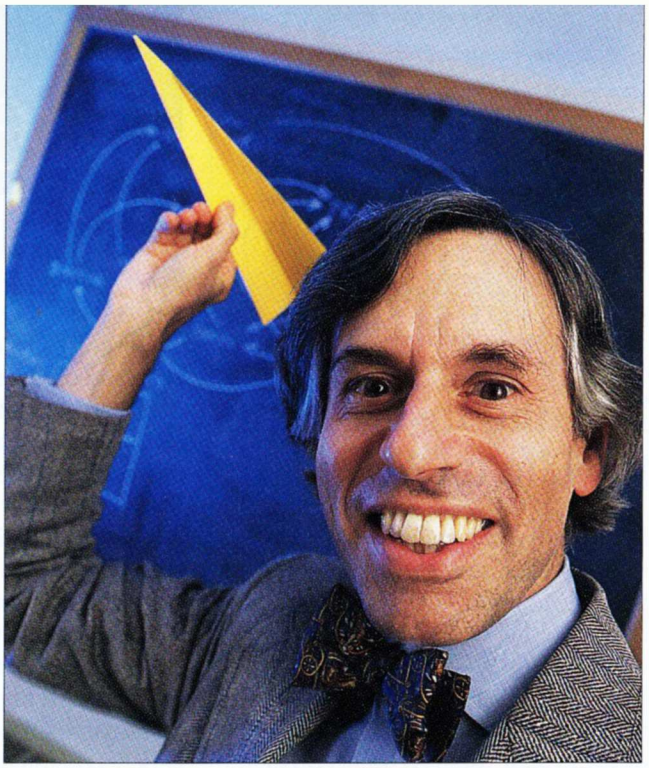
Weil is quick to rattle off other ways companies can maintain their positions in maturing markets, such as outsourcing key components of their work and packaging their products with new services to retain customer loyalty. Eventually, he notes, they may simply have to develop new products or niches and move on.

Weil stresses that computer simulation can serve as a teaching tool by allowing companies to test out ideas and strategies in advance. Simulations can also help overcome organizational inertia: experimenting with different options can help managers generate evidence to persuade senior executives of the need for change.

Graham Hillier, planning and quality manager of ICI's petrochemicals and fertilizers division, says using Weil's model has helped managers stop basing decisions "on gut feelings." In particular, he hopes it will improve the company's forecasting, which has tended to be overly cautious: "The model has shown us that we tend to underforecast peaks and overforecast troughs. We get the pattern right, but the change is much bigger than we expect." By playing it too safe, the company may not have taken full advantage of opportunities presented in the market.

Both organizational and technological innovation, Weil says, can play a crucial role in helping a company break out of the commodity cycle. For companies that desperately need to innovate, he adds, his simulation provides "a tool for reducing the risk of failure."

— *Caroline T. Chauncey*



Henry Birdseye Weil, a senior lecturer at MIT's Sloan School of Management, says his computer simulation based on the airline industry can help technology-based businesses break free of the price competition that chokes off innovation.

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Trends

INNOVATIONS FROM THE WORLD OF TECHNOLOGY

PLANETARY BIOLOGY

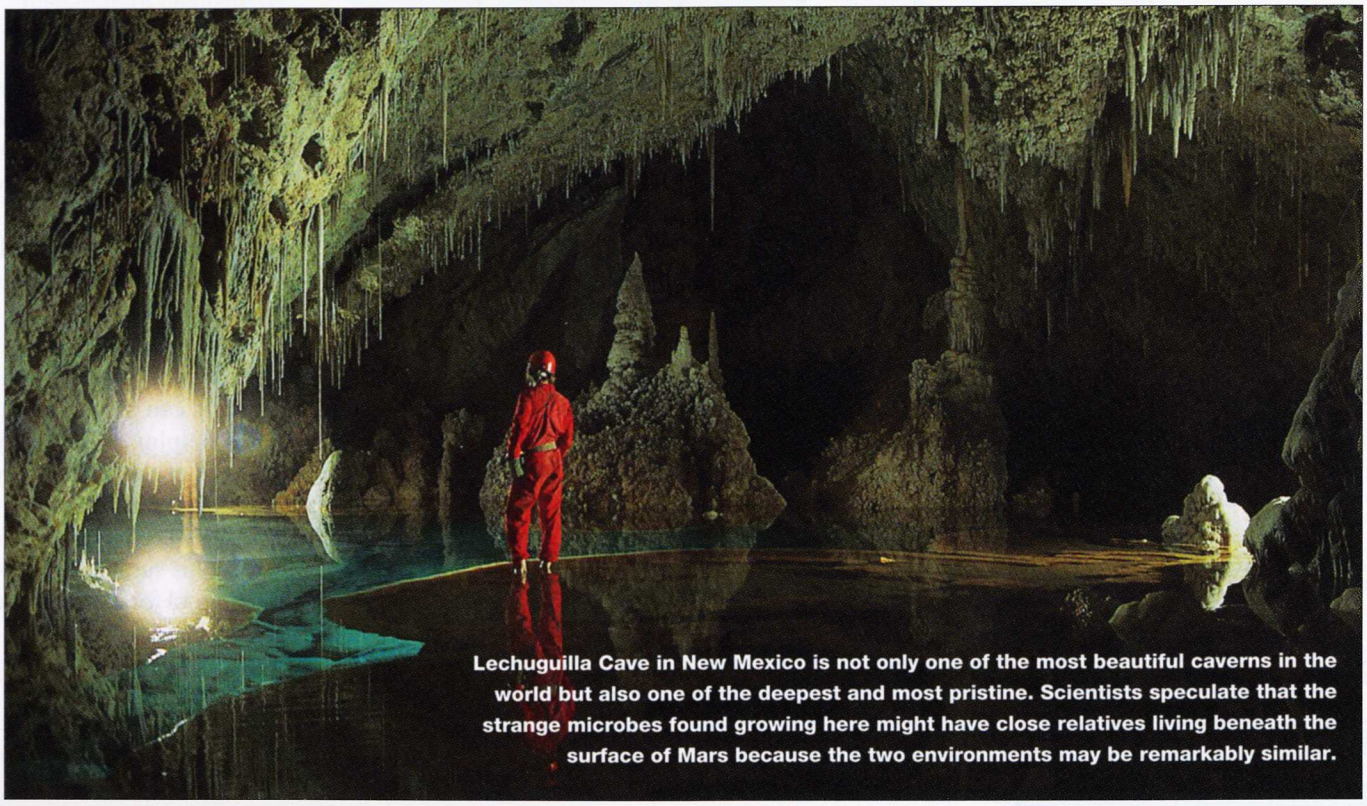
Looking Inside Earth for Life on Mars

It's your typical spelunking saga: You squirm through tunnels no wider than a watermelon in diameter, then rappel over the edge of a 200-foot cliff into a void so black you can't even see your feet, let alone the bottom—assuming there is a bottom. If you survive that ordeal, you'll still have to negotiate the slippery slope of the "Freakout Traverse" or the dreaded crevasse known as the "Great White Rift." A subterranean tour through Lechuguilla Cave in New Mexico might also include other highlights and lowlights: "Misery Hole," "Death Pit," and the "Parallel Universe."

Some explorers enjoy the thrill of probing an uncharted, underground wilderness. Others find solace in the quiet and darkness of America's deepest cave, which extends more than 1,500 feet below the surface. Then there are those who come searching for life on Mars.

Life on Mars? Indeed, as scientists explore the Red Planet via the Mars Pathfinder and a series of subsequent NASA missions planned over the next decade, other researchers are studying the microbial lifeforms that inhabit this vast cave in Carlsbad Caverns National Park, evaluating the possibility of analogous creatures lurking beneath the Martian surface. This work has been supported by NASA's exobiology program from a budget designated for the study of "terrestrial analogs" to other planets. "We're reconsidering the subsurface environment on Mars partly because the subsurface on earth is turning out to be very rich," says Penny Boston, a biologist and NASA consultant at Complex Systems Research in Boulder, Colo. In fact, scientists are finding microorganisms almost everywhere they look—near vents on the floor of the deep ocean, inside Antarctic rocks, and at oil- and gas-drilling sites, thousands of feet underground.

The basic premise of the analogy to life on Mars goes like this: Some three to four billion years ago, Mars was a warmer and wetter place owing, in part, to a thick atmosphere of carbon dioxide that heated the planet through the greenhouse effect. Eventually this carbon dioxide combined with water to form carbonic acid which, in turn, reacted with rocks on the surface to create carbonates such as limestone and dolomite. This process depleted the carbon dioxide in the atmosphere, leaving the surface frozen and inhospitable with no liquid water to be found anywhere. "Now we're saying that if life couldn't have survived on the surface, maybe it moved

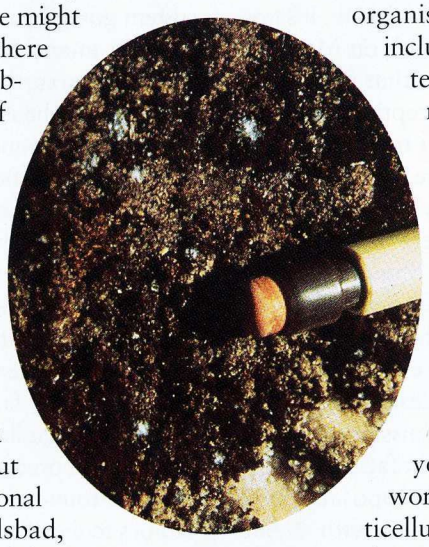


Lechuguilla Cave in New Mexico is not only one of the most beautiful caverns in the world but also one of the deepest and most pristine. Scientists speculate that the strange microbes found growing here might have close relatives living beneath the surface of Mars because the two environments may be remarkably similar.

PHOTO: DAVE BUNNELL

underground," explains Christopher McKay, a planetary scientist at NASA's Ames Laboratory who has accompanied Boston and others on several Lechuguilla expeditions.

The entrance pit to Lechuguilla cave was discovered in 1914. But it wasn't until the 1950s that investigators began to suspect there might be a cavern somewhere beneath the pile of rubble on the bottom of this pit. Once the rubble wall was eventually broken through in 1986, intrepid spelunkers tunneled in and began to chart more than 90 miles of passages. The full extent of Lechuguilla is not yet known, but Dale Pate of the National Park Service in Carlsbad, N. Mex., is convinced that "there's a lot more cave out there than we know about, possibly 1,000 or 2,000 miles worth."



Clinging to the walls of the cave, a fluffy, dark residue that feels like wet, graphite cotton candy is one of many strange formations that contain previously unknown bacteria and fungi.

Some call it the most beautiful cave in the world, with brilliant colors, pristine pools, and spectacular mineral formations that resemble flowers, crystals, chandeliers, and coral. Although scientists can appreciate this splendor, they are drawn to the cave mainly because it is the perfect place to study a virtually uncontaminated underground environment. "We do our best to limit the impact because we don't want to contaminate and destroy the thing we hope to study," Boston explains. "We're looking for exotic organisms that are easy to distinguish from contaminants brought in by humans. But if we're not careful, these contaminants might outcompete indigenous organisms."

Lechuguilla, a world unto itself, has no large natural openings, which means that very little air or water flows in from the outside. The cave is also of geologic interest because of its rich sulfur deposits. Various microorganisms have been found on earth that derive energy from sulfur, and similar lifeforms may exist on Mars, which both the Viking and Pathfinder missions have shown has a high sulfur content.

"A highly diverse group of organisms lives in the cave, including numerous bacterial strains we've never seen before," notes Larry Mallory, a microbiologist at the University of Delaware's Center for Marine Biotechnology, who has made repeated visits to Lechuguilla since 1992. "A quarter mile down, you enter a microbial world. There are no multicellular lifeforms beyond that point except for cavers."

So far, hundreds of microbial strains have been found in the cave, the bulk of which are previously unknown, says Boston. Ultimately, she and her colleague, University of New Mexico biologist Diana Northup, plan to examine the DNA of the microbes to compare it with the DNA of known microbes. "We're trying to find the closest relatives of these strains, figure out where they came from—the soil or ancient ocean—and determine how long they've been separated from the world above," Boston says.

The researchers also hope to determine the energy source that drives this sunless ecosystem. "The key is finding organisms that can make food by chemical means," McKay explains. Mallory has identified a strain of bacteria that oxidizes manganese, but he is still trying to determine whether the creatures actually derive energy from that process. On subsequent trips, he plans to search for iron-oxidizing bacteria at the "Rusti-

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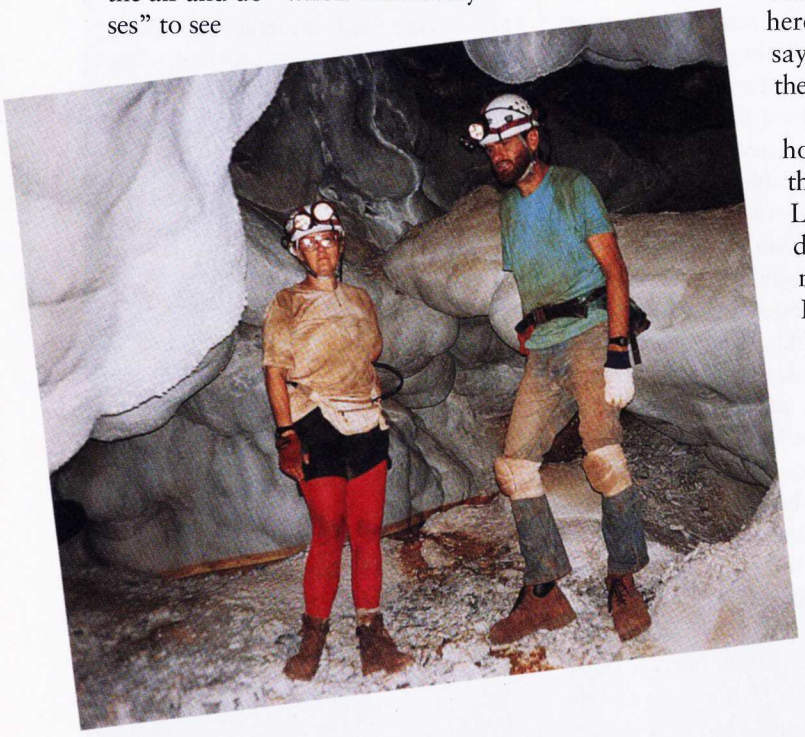
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PHOTO: NASA

cles," an iron formation in the northeast portion of the cave that looks like a "runny popsicle." Boston also intends to gather more samples in the hopes of capturing both iron- and sulfur-oxidizing organisms.

Figuring out what these "bugs" eat is a tough problem, she says. The most likely food sources are either in the air or in the rocks. If adequate funding can be secured, she and Northup hope to conduct gas chromatography studies of the air and do "whole-rock analyses" to see what in the rock wall is edible.



Drawing on research from several expeditions to Lechuguilla cave, NASA planetary scientist Christopher McKay (right) and biologist Penny Boston (left) hope to determine where and how future space probes should look for signs of life on Mars.

Boston has already had close encounters with some weird things growing in the cave, such as an odd fluffy material called "gorilla drek" that clings to the crumbling cavern walls. "It feels like wet, graphite cotton candy," she says. "When you put it between your fingers, it wilts down to nothingness." The scientists eventually determined that bacteria and fungi live in the fluff, but Boston suspected that from the start: "It gave me an eye infection, which made me think that something was growing there."

The "gorilla drek" episode taught Boston an important lesson: "It's difficult to tell when things are alive, even with a whole crew of investigators crawling around, taking samples, and examining them later in the lab. It's possible that when we look on Mars, we won't find organisms that fit our preconceptions." Detection tools that work here on earth, she says, may not work there.

She and McKay hope to draw on their experiences in Lechuguilla while designing pending missions to Mars. In fact, both have proposals pending with NASA for the 2001 Mars Surveyor mission. "By looking at life underground on earth, we hope to determine whether it's reasonable to look for life underground on Mars, figure out how deep to look, and see if there might be fossil remnants we could recognize," McKay says.

"We'd like to know what kind of clues these bugs might leave behind," Boston adds. If life on Mars retreated to the subsurface and then died out, there still might be a variety of "signatures"—actual fossils, geochemical traces, tell-tale isotopic shifts, or characteristic weathering patterns on the surface of rocks. "Studying a community in a cave that died out and gets fossilized may help us know what to look for in a radically different environment."

The studies of Lechuguilla could shed light on other questions pertaining to the smallest closed ecosystem that can survive. "Some argue that it takes a whole planet to sustain an ecosystem; others claim you could keep a viable system going in a bottle," Boston says. "It's an unanswered question that is applicable to earth or any other planet."

Although she is still heavily invested in Mars, and even calls herself a "Martian" at times, Boston acknowledges that the research at Lechuguilla will be of interest for terrestrial biology, independent of extraterrestrial concerns. Mallory agrees, saying that the cave research can contribute to our understanding of where life exists on this planet and how far down it goes.

The Lechuguilla work may also have a number of practical applications. Mallory has founded a corporation called Biomes to test the disease-fighting capabilities of cave organisms and their byproducts. Some organisms appear to produce compounds that are specifically toxic to certain types of breast cancer cells. He is also investigating the antibacterial, antiviral, and antifungal properties of other compounds derived from the cave.

The exploration of Lechuguilla, meanwhile, is proceeding slowly, given the difficulties of underground navigation, plus the fact that admittance to the cave is severely restricted by the National Park Service. The cave is closed to visitation except for research and maintenance, and the park service lets in only about half a dozen research teams a year. Boston is happy to be among the few admitted, offsetting to some extent her concern that humans may not set foot on the Red Planet for quite a long while. For now, she consoles herself by saying, "This cave is my Mars."

—*Steve Nadis*



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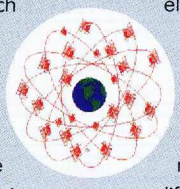
PHOTO: NASA

ATMOSPHERIC SCIENCE

Detecting Earthquakes from Space

In these days of budgetary restraint, scientists are touting what may be the ideal instrument for studying the ionosphere, the lofty atmospheric layer extending some 50 to 400 miles above the earth's surface. This instrument, they say, could probe the ionosphere in greater detail than has ever been done before. Best of all, the device already exists.

Geophysicists Eric Calais of the University of Nice in France and Bernard Minster of the Scripps Institution of Oceanography in San Diego submit that the Global Positioning System (GPS), a network of satellites and ground stations used for pinpointing positions on earth, gathers a wealth of data about the ionosphere that remains largely untapped. GPS satellites constantly broadcast radio signals to ground-based receivers. These signals don't reach the surface undisturbed, however. Instead, the radio beams are slowed by interactions with electrons in the ionosphere. By monitoring signal travel times, scientists can obtain a direct measure of how the electron density fluctuates over time—changes that are important, among other reasons, because they disrupt radio communications.

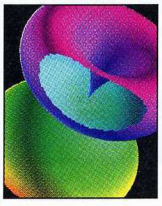


Calais and Minster have shown that earthquakes, quarry blasts, and even rocket launches produce detectable disturbances in the ionosphere. The displacement of the ground from an earthquake, for example, pushes the atmosphere, producing a wave that propagates upward. When the wave passes through the ionosphere, it moves electrons up and then down, periodically changing the electron density at a given altitude. An underground nuclear test would cause a different pattern of ground displacement, ultimately leading to a characteristically distinct ionospheric disturbance.

For this reason, the GPS could be used to discriminate between such explosions and earthquakes, serving as a tool for verifying the Nuclear Test Ban Treaty that would complement standard seismographic techniques. Moreover, by understanding how electrons in the ionosphere are perturbed by earthquakes, explosions, and rocket launches, Calais and Minster also hope to be able to predict how magnetic storms from the sun will affect radio communications that involve bouncing UHF waves off the dense clustering of electrons in the ionosphere.

Their long-range goal is to take advantage of these terrestrial and extraterrestrial rumblings to gain a more accurate picture of the ionosphere's day-to-day workings. Moreover, Calais notes, "the technique barely costs anything, because the satellites and receivers are already in place. The data keeps pouring in, and we just have to listen."—STEVE NADIS

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CYBERSPACE

Preventing Culture Clash on the World Wide Web

When Japanese tourists travel to the United States, many flock to shopping malls to stock up on American goods that are in short supply in Japan, especially computer and entertainment products. Thus it should come as no surprise that a growing number of U.S. exporters are vying for Japanese consumer business through retail shops on the World Wide Web. But according to a new study, if Web entrepreneurs hope to be successful, they had better pay close attention to the special requirements of Japan's Web users.

The Internet is often thought to have a unique culture that supersedes local or ethnic distinctions. But in Japan, economic conditions have had a major impact on the evolution of Japanese cyberculture, according to a report published by market researchers TK Associates International of Portland, Ore., and Yahoo Japan and Nikkei Research in Japan. The report (available on the Web at www.tkai.com) suggests that while many U.S. Net enthusiasts surf the Web for hours on end, sampling sites jammed with information and elaborate graphic images, a less freewheeling cyberculture has evolved in Japan.

The main reason for this difference is the high cost of connectivity in Japan, says Tim Clark, president of TK Associates. In fact, he says, a typical Japanese Internet user pays about $100 a month to spend an hour a day online. This charge includes about $40 per month for Internet service, $15 per month for basic phone service, and $48 for 30 hours of telephone time (at 8¢ per 3 minutes of local calling). In the United States, users spend less than half that much for unlimited access. The major difference is that although U.S. users typically pay a flat monthly telephone service fee of around $25 and about $20 per month to an Internet service provider (ISP), the phone company allows them to make unlimited local phone calls and spend as much time online as they wish at no extra charge.

Japan's high phone rates have not diminished Japanese fascination with cyberspace, however. The world's second-largest economy also ranks next to the United States in total numbers of Internet users. And the future looks bright for Japanese Web commerce. Approximately 23 percent of the Nikkei-Yahoo survey group have bought products on the Web, the most popular of which include personal-computer software as well as games, books, compact disks, videos, and apparel. And two-thirds of PC owners in Japan who haven't shopped on the Web say they would like to buy an item online. Perhaps most encouraging for U.S. Web marketers, a TK Associates survey of 1,100 Japanese Internet shoppers found that 60 percent have purchased products from cyberstores based outside of Japan.



The key for U.S. Web merchants hoping to reach the Japanese online market—which ranks second only to the United States in size—is to follow proper etiquette. The biggest sin to avoid is the use of glitzy but slow-loading and memory-hogging graphics. Also important is to provide a Japanese-language version of your home page.

Some U.S. Web merchants are already building a loyal base of Japanese customers. Cyberian Outpost, an online computer retailer in Connecticut, is registering $300,000 in sales and attracting nearly 50,000 visitors a month from Japan. Bargain America, a Web distributor that offers products

from some 250 firms, is drawing 50,000 Japanese visitors a month, says William Brissman, vice-president for marketing. The company, rated in 1996 by Japan's *Nikkei Sangyo Shimbun*, a daily business newspaper, as the most popular U.S. commercial Web site in Japan, has received more than 100,000 catalog requests from Japanese consumers in the past year, and generates a daily order volume "in the four-figure range," Brissman says.

Web-based distributor Virtual Vineyards has attracted a significant level of business from Japanese consumers thanks to favorable articles appearing in Japanese periodicals, according to marketing manager Carolyn Sproule. She says Japanese customers typically place larger orders than U.S. consumers, in part to offset the per-bottle costs of shipping the California company's products across the Pacific.

While companies are understandably reluctant to divulge detailed marketing strategies, these entrepreneurs offer a few basic rules for reaching the Japanese market. One is to avoid creating Web sites with memory-hogging images that slow down loading time. Because of the high phone charges, "fast-loading pages is the Japanese Web surfer's number one requirement for a compelling Web site," says Clark.

Another key is for retailers to address Japanese buyers in their own language. "All Japanese take six years of English in school, but many are rusty in the language," Brissman says. Bargain America has a Japanese-language Web site, and Cyberian Outpost's Web site offers Japanese-language descriptions, including a frequently-asked-questions page and guidelines for ordering products. The computer retailer also includes on its site a translation package that converts English into a variety of languages, including Japanese. And Virtual Vineyards posts pages that welcome first-time visitors and provide ordering information in Japanese.

Promoting Web sites in print has also proven an effective tactic. Both Cyberian Outpost and Bargain America have used banner ads on the Web, but they have found off-Web promotions to be of greater benefit in reaching customers. Both have purchased advertisements in print magazines, including those that review Japanese Web sites, and have had even greater success distributing e-mail newsletters to customers.

Quality of customer service is another key factor. Brissman says Bargain America finds Japanese consumers even more demanding than American shoppers regarding meticulous product condition and packaging. Ataru Onuma, a Tokyo business consultant who specializes in helping penetrate the Japanese market, concurs, adding that Japanese consumers want customer-service centers they can call to make complaints, track orders, or get product information from a company representative who speaks their language.

Clark of TK Associates cautions that U.S. companies should be careful not to project the irreverent tone that works so well in reaching American Web audiences. "Japan's Internet is, for lack of a better phrase, relatively 'pure and innocent,'" he explains. "This is largely a reflection of Japanese culture; there is almost no political satire on TV and other media, for example."

Still, it's difficult for U.S. businesspeople to avoid cross-cultural miscommunications. Last October, Virtual Vineyards sent out a Halloween e-mail newsletter with a subject line reading "Boo!" Some Japanese customers misunderstood the reference, Sproule says, because they thought the word meant to pass gas.

Finally, Web retailers and market researchers alike advise reducing confusion over pricing and payment mechanisms. Onuma points out that Japanese consumers are afraid of risking unfavorable currency exchanges when dealing with international companies, so he recommends that online retailers offer a yen payment option that helps customers immediately grasp prices in their own terms. —*Mark Hodges*

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TRANSPORTATION

Heavenly Highways for Cyclists

Though bicycles are the most widely used vehicles in the world, as well as the most energy efficient, they still play a minor role in the U.S. transportation system. The problem, according to many observers, relates to infrastructure. "Technical advances are leading to faster and faster bikes, but we don't have the facilities to accommodate them," says Milnor Senior, head of Bicycle Transportation Systems, Inc. in Denver. Safety is a related concern. "In so many places, there's too much hazard, or perceived hazard, for cyclists to get out into traffic without putting their lives at risk," notes Gerry Hawkes, president of Bike Track, Inc. in Woodstock, Vt.

Both Senior and Hawkes hope to change this situation with their plans for new kinds of bike conveyances. Senior's scheme, "TransGlide 2000," consists of a four-lane "transportation corridor," placed either on the ground or elevated above roadways. The system, he says, is intended to move people through an urban area with the "highest average speed and lowest cost."

Senior proposes installing fans in the enclosed one-way tunnels to eliminate 90 percent of the air resistance cyclists normally face. He estimates that just 11 fans, each powered by a 150-horsepower electric motor—and costing $200 per hour, in all, to operate—could provide the requisite tailwind over a 10-mile stretch of weather-protected bikeway.

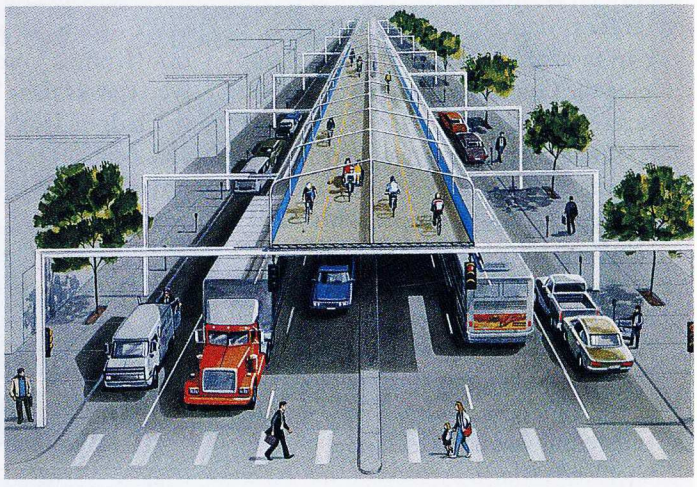
Enabling average speeds of about 25 miles per hour, the system would provide the same capacity as a light rail transit line at a fraction of the cost, Senior maintains—about $8 million per mile, he says, versus more than $80 million per mile. He has not yet secured the funding he needs to build a demonstration prototype, but is filing proposals with the National Park System in the hopes of testing the concept at a U.S. park.

Hawkes, meanwhile, is proposing a less elaborate system that could be implemented much more quickly—practically overnight, he contends. His EcoTrack transportation path consists of interlocking pre-fab sections—composed largely of recycled polyethylene plastic—that can be snapped together and laid down over fields, beaches, and other terrain. It's so easy to install, Hawkes says, that one worker "could put down about 500 feet in an hour on level ground." (Installation on uneven terrain is also manageable but more time consuming.) The cost per mile of track, depending on the width, would range from $100,000 to $250,000. The no-frills system could be upgraded, at additional cost, to include safety railings, wind and splash barriers, and canopies.

In contrast to paved paths, which require heavy equipment to lay down, EcoTrack could be installed with minimal damage to the soil and vegetation, says Hawkes, who also happens to be a forester. The track could also be removed almost instantly, if required.

EcoTrack has held up well under heavy use during the past two years on a 100-foot-long stretch of bike path along the Cape Cod National Seashore. Because of the success of the test track, Hawkes is developing plans for mass production capability.

Although it is possible—and some would say likely—that neither TransGlide 2000 nor EcoTrack will take the country by storm, both systems illustrate that creative approaches are needed, and indeed available, to elevate the status of the lowly bicycle in America's transportation mix.—*STEVE NADIS*

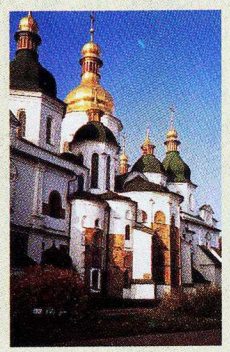


Entrepreneur Milnor Senior, head of Bicycle Transportation Systems in Denver, hopes to spur interest for his plan to build an elevated four-lane commuter bikeway that he says would provide the same capacity as a light-rail transit line at a fraction of the cost.



ILLUSTRATIONS: BICYCLE TRANSPORTATION SYSTEMS, INC.

Discover...



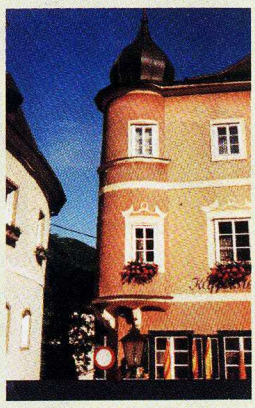
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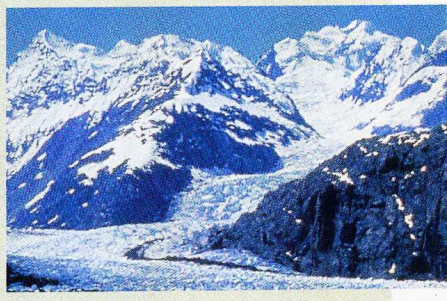


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ENVIRONMENT

Greener Dry Cleaners

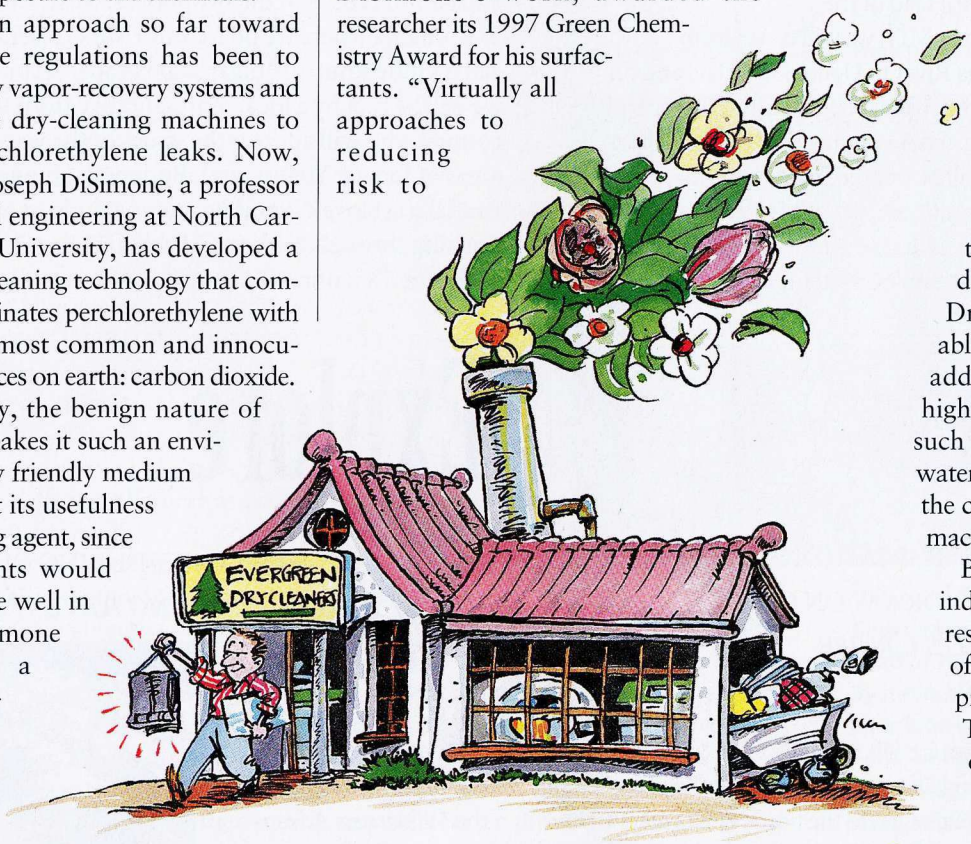
Dry cleaning has long been a prime target on every environmentalist's hit list. Its main cleaning agent—perchlorethylene—is a volatile organic solvent whose toxic emissions cause headaches, dizziness, and nausea after short-term exposure and liver and kidney damage over the long term. In fact, all dry cleaners are required by law to protect employees from exposure to the chemicals.

The main approach so far toward meeting the regulations has been to install costly vapor-recovery systems and seal up the dry-cleaning machines to reduce perchlorethylene leaks. Now, however, Joseph DiSimone, a professor of chemical engineering at North Carolina State University, has developed a novel dry cleaning technology that completely eliminates perchlorethylene with one of the most common and innocuous substances on earth: carbon dioxide.

Normally, the benign nature of CO_2 that makes it such an environmentally friendly medium would limit its usefulness as a cleaning agent, since contaminants would not dissolve well in it. But DiSimone discovered a unique surfactant, or detergent, whose molecules have an affinity for oils and dirt on one end and for CO_2 on the other. When mixed in liquid CO_2, the surfactant organizes into clusters, called micelles, that capture dirt and grease as garments are immersed in the solution. Unlike conventional dry cleaning, which creates toxic waste, all that is left over from DiSimone's technique is liquid CO_2 and dirty surfactant, both of which are harmless and recyclable.

DiSimone discovered the substance several years ago while working on a process to use CO_2 as a solvent in making acrylic polymers. He has since started Micell Technologies, Inc. in Raleigh, N.C., to commercialize the process. The company joined with American Dryer Corp. of Fall River, Mass., to build a 100-gallon dry cleaning machine that it hopes to unveil early next year in North Carolina.

The technology has already won raves from the federal government. Last June, the U.S. Environmental Protection Agency, which has funded much of DiSimone's work, awarded the researcher its 1997 Green Chemistry Award for his surfactants. "Virtually all approaches to reducing risk to human health so far have been to reduce exposure" to toxic chemicals and solvents such as perchlorethylene, says Paul Anastas of the EPA's Office of Pollution Prevention. But in so-called "green chemistry" programs like this, he says, the aim is to reduce or eliminate the intrinsic hazard by finding replacements for polluting technologies.



Lienhart says Micell hopes to sell machines to dry cleaners along with regular shipments of surfactants. The process produces so little waste, he says, that Micell will have store owners ship back the dirty surfactants for recycling.

Lienhart figures that a process enabling operators to clean a broader variety of fabrics with less labor and no environmental headaches will provide enough of an incentive for business owners to accept the higher cost of the machines—$125,000, about twice the cost of perchlorethylene machines.

Several other cost-saving considerations also weigh in favor of CO_2 cleaning. Because the units must operate at high pressure—about 900 pounds per square inch to keep the CO_2 liquefied—cleaning can be done at roughly room temperature, eliminating the likelihood of heat damage to garments. Dry cleaners will also be able to use the machines to add coatings that require high-pressure application, such as stain resistance or water repellents, eliminating the cost of separate coating machines.

Beyond the cleaning industry, Micell has been researching the possibility of using a carbon-dioxide process to dye fabrics. Tremendous amounts of water and heat are now used to set dyes in fabrics, Lienhart says. A deeply penetrating CO_2 process performed at room temperature could accomplish huge savings.

The company has also been talking with institutional dry cleaners, and even the Navy, which Lienhart notes is "interested in getting perchlorethylene off their ships." The company is also eyeing other niches in the huge industry of organic solvents, including the cleaning of precision machine parts.

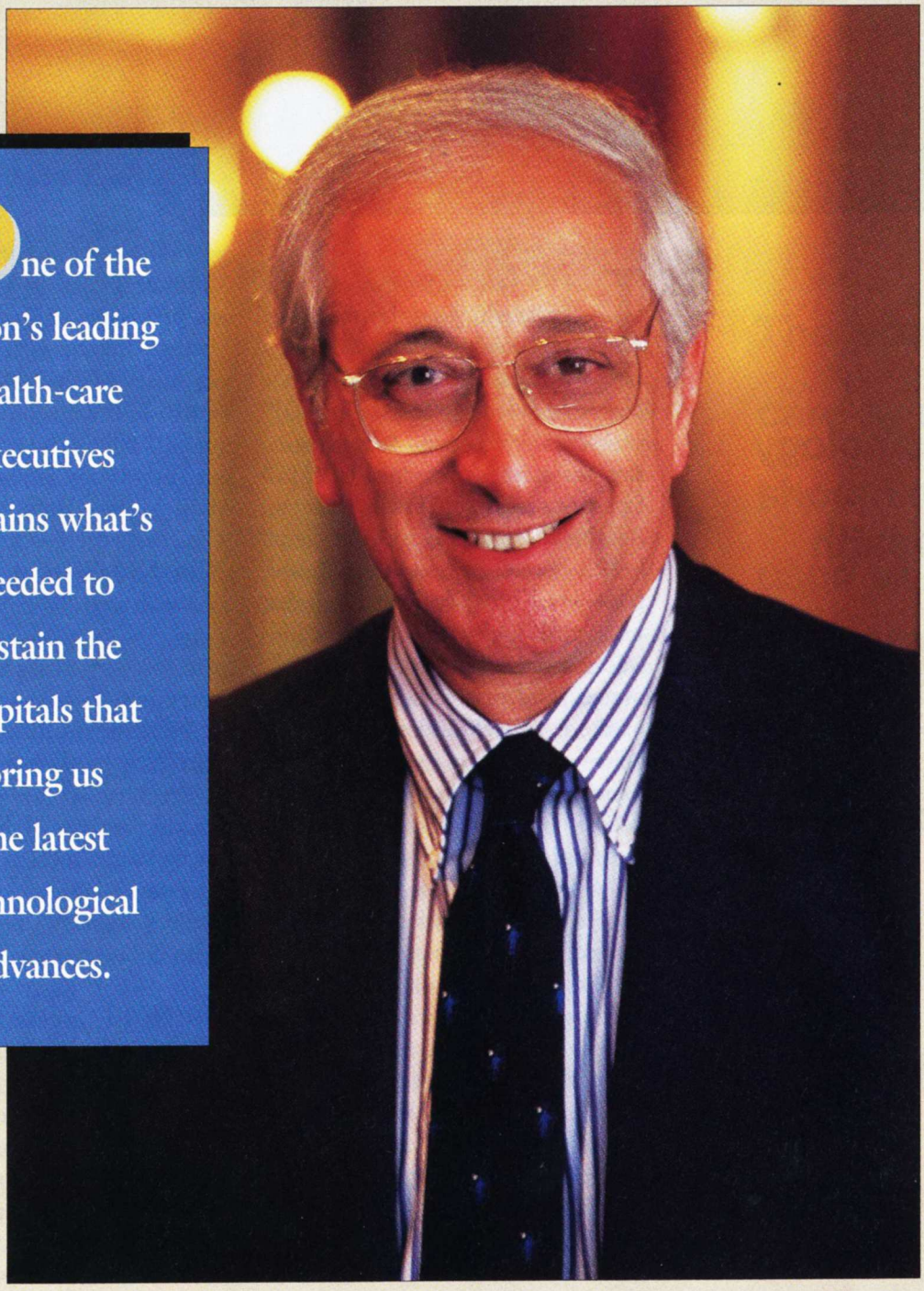
—*MARK WARD*

ILLUSTRATION: JON McINTOSH

AN INTERVIEW WITH SAMUEL O. THIER

Strong Medicine

One of the nation's leading health-care executives explains what's needed to sustain the hospitals that bring us the latest technological advances.



PHOTOS BY FRANK SITEMAN



To assume that technology raises health care costs is silly.

LET'S face facts: even though folks who read this magazine presumably hold the research process in high regard, the phrase "academic research hospital" probably doesn't sound as exciting as, say, the mow-down spirit of Wall Street or the Tyson-Holyfield match. But think again. In today's free-for-all health-care market, academic hospitals—which conduct the research that undergirds high-tech medicine, educate new doctors about the latest techniques, and apply those tools and methods to rich and poor patients alike—are battling to maintain their financial strength in the face of competition from for-profit hospitals. Exciting?

"A little too exciting," says Samuel O. Thier, president and chief executive officer of Partners HealthCare System. That nonprofit Boston-based organization includes two of the largest and most respected teaching hospitals in the country, Massachusetts General and the Brigham and Women's, as well as three other teaching hospitals and a network of more than 750 separate primary-care doctors. "You have to remember that this isn't a game; we're talking about health care for people."

Thier, former president of the National Academy of Science's Institute of Medicine, spent three years as president of Brandeis University before taking the reins of Massachusetts General and creating the Partners system, which had revenues of $2.1 billion in its fiscal year 1996.

Technology Review senior editor Laura van Dam recently asked Thier whether—and how—to maintain the traditional missions of academic hospitals.

TR: Some critics say that the competition among hospitals today stems from rising health-care costs that in turn have partly come about because every hospital has felt obliged to acquire and use high-priced medical technologies such as MRI (magnetic-resonance-imaging) machines. Does the development of new technologies help or hurt financially?

THIER: To assume that technology raises health-care costs is silly. Depending on the particular technology and its use, it can cost more, save money, or be neutral. Look at the lithotriptor, a shock-wave machine that costs $1.5 million and blows up kidney stones. Previously surgeons had to remove kidney stones from patients who then might stay in the hospital four or five days and could be out of work for a



month. With lithotripty patients go home the same day and are back at work in two days. That means major savings to the economy.

Partners HealthCare has just formed the Center for Innovative Minimally Invasive Technology, which is developing ways to improve diagnoses and treatments with less trauma to the patient. That can translate into fewer medical problems, which in turn can reduce the time patients have to spend in hospitals. Whereas we used to open the abdomen to remove somebody's gall bladder, with minimally invasive technology we can now take the gall bladder out through a little tube called a laparoscope. We're also doing research with a new MRI unit that lets surgeons operate on the brain while they're looking at MRI images. Previously surgeons couldn't do both tasks at once. That made brain surgery trickier and sometimes longer.

Maintaining the level of medical-technology research we've had is important in this era of managed care. Already, physicians in the regions with the highest penetration of managed-care facilities show a fall-off in clinical-research publications and grants. This suggests that doctors are being pulled away from those responsibilities to see more and more patients.

I'm not saying managed care is bad—in fact, Partners is all for it and very much takes part in it—but it should not be used to promote the lowest-cost care at the expense of research on better treatments.

TR: Should academic hospitals also continue to provide health care to anyone who needs it?

THIER: Yes. Both academic and community nonprofit hospitals play critical roles in providing care for the 40 million people—two-thirds of whom are working—who don't have private insurance or governmental medical assistance for at least part of the year.

Unfortunately, as the for-profit motive in health care continues to play out we are going to end up with patient populations that are not served. Nonprofit hospitals are not going to do well compared with for-profit institutions should the nonprofits continue to provide care for those who lack any insurance. If a for-profit institution takes over a nonprofit hospital and sends the indigent who once used that facility to us, the number of people we serve at no cost rises. Economically, in this situation a private organization purchases a public asset

The managed-care system should not be used to promote the lowest-cost care at the expense of research on better treatments.

If you are a major employer, you can look at "outcomes" research and decide which health-care system offers the best quality for your employees.

without maintaining the public responsibility of the formerly nonprofit hospital.

TR: So how can academic hospitals continue to compete with for-profits?

THIER: Partly by stressing quality. Toward that end nonprofit hospitals—particularly the academic ones—can strengthen their market position by improving their "outcomes" research.

Studies of how patients fare from their treatments indicate the quality of hospitals' services. Because of their broader array of specialized services and pool of newly trained doctors who are up-to-date on the latest medical knowledge and techniques, academic hospitals should offer better quality than for-profit hospitals. In fact, a study of 30 hospitals in Ohio—which was recently published in the *Journal of the American Medical Association*—found that major teaching hospitals had lower death rates, after adjusting for the severity of patients' illnesses upon arrival, than nonteaching and small teaching hospitals.

If you are a major employer, you can look at the outcomes research coming from the three or four health-care systems in your region and decide which system, including which hospital, offers the best quality for your employees.

TR: Aren't employers going to base their decisions primarily on cost?

THIER: No. General Motors offers a good example. This year that company began to pay a significant amount of the cost for its employees to belong to the managed-care provider GM thinks upholds the best-quality standards on factors such as health outcomes, doctors' and nurses' qualifications, facilities, and convenience. GM employees can still purchase services from other groups, but they have to pay a larger percentage of the costs charged by those insurers.

TR: Could GM's interest in quality of care be an exception?

THIER: Other entities are starting to show interest. The Cleveland business community has banded together and demanded that hospitals provide information on their complications and death rates related to medical procedures.

TR: But aren't academic hospitals such as those in the Partners system, like many health-care providers, starting to require doctors to see a set number of patients, leading to complaints about patient visits and hospital stays that are too short?

THIER: In this marketplace all hospitals must set guidelines on matters such as numbers of patients seen, using industry standards, but for our part we factor in the number of older or sicker patients various doctors' groups are likely to see. Physicians at Massachusetts General and the Brigham and Women's hospitals, for instance, tend to have sicker patients, so we have to take that into account. We do not have a cookie-cutter, one-size-fits-all approach.

Standards are critical—how can we even measure quality without having them?—but they should be used to improve the results of care rather than just efficiency. And that's what academic hospitals should focus on as we compete with for-profits.

We also need another boost. An independent task force I'm chairing—organized by the Commonwealth Fund, a philanthropic foundation—has found that the clinical services of academic hospitals can't fully compete



on a cost basis with those of for-profit hospitals. That's because we care for these patients who cannot pay and we subsidize research. (The National Institutes of Health under-reimburse overhead to ensure cost-sharing by grantee institutions.) We need a trust fund that pays for those services as social goods so that we play on a level field. The federal government should require Medicare, Medicaid, and health insurers to share in financing this fund. Our report also calls for setting up an independent, nongovernmental overseer of the fund to ensure that the money is used appropriately.

TR: What could convince the federal government to agree to finance the fund?

THIER: Congress already agreed to this general notion once, in the Balanced Budget Act of 1995, but President Clinton vetoed that for other reasons. Whether the idea will be reintroduced is unclear, but it should be.

Meanwhile, both federal and state legislatures can help with academic hospitals' higher costs by insuring at least some coverage for those who really need it. One beginning step has occurred in Massachusetts, for example, where the legislature has determined that hospitals, the state government, employers, and health-care insurers will all contribute to the cost of care for people without any insurance. This is a wonderfully creative approach, as long as insurers don't turn around and start paying hospitals less for their work. Other states should copy the model.

As a decent society, we should especially make sure that all kids are covered. If we consider such efforts in only the most hard-headed way, we should realize that because the first two to five years of youngsters' lives are critically important in terms of their future health, their future productivity and participation in society are at stake.

Generally, as a society we need to think about the responsibilities of medicine as a profession. According to a definition proposed by Louis Brandeis, the former Supreme Court justice, a profession must have standards that its members enforce. He said a profession needs to advance and pass on a body of knowledge. That means we must conduct research and teach. According to Brandeis, a profession adheres to a code of ethics and values performance above reward. That's the commitment to provide health care whether or not somebody can pay for it. ■

We should make sure all kids have health coverage. Their future productivity and participation in society are at stake.

Food Irradiation

Will It Keep the Doctor Away?

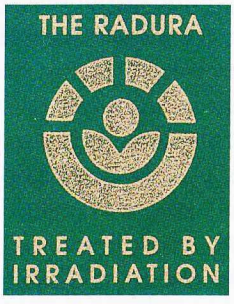
EVERY MAJOR FOOD AND HEALTH ORGANIZATION HAS ENDORSED FOOD IRRADIATION AS A FOOLPROOF AND SAFE WAY TO RID OUR FOOD SUPPLY OF DISEASE-CAUSING MICROBES. THEN WHY AREN'T WE USING IT?

In food we trust. That motto guides us as much as the one that graces our currency. We take for granted the food we buy in grocery stores or eat in restaurants, trusting implicitly that it will satisfy our hunger, build strong bodies 12 ways, and keep us healthy.

That trust may be a bit misplaced. Nearly 200 people in the United States, most of them children or elderly, die each week from illnesses they contract from food. Estimates from the Centers for Disease Control and Prevention in Washington, D.C., suggest that 6 to 33 million people are stricken with food-borne diseases each year. Major outbreaks are grabbing headlines with greater frequency—consider the recent Hudson Foods recall of 25 million pounds of bacteria-tainted beef, contaminated Jack-in-the-Box hamburgers, Odwalla apple juice, and Guatemalan raspberries—while many minor ones go unreported.

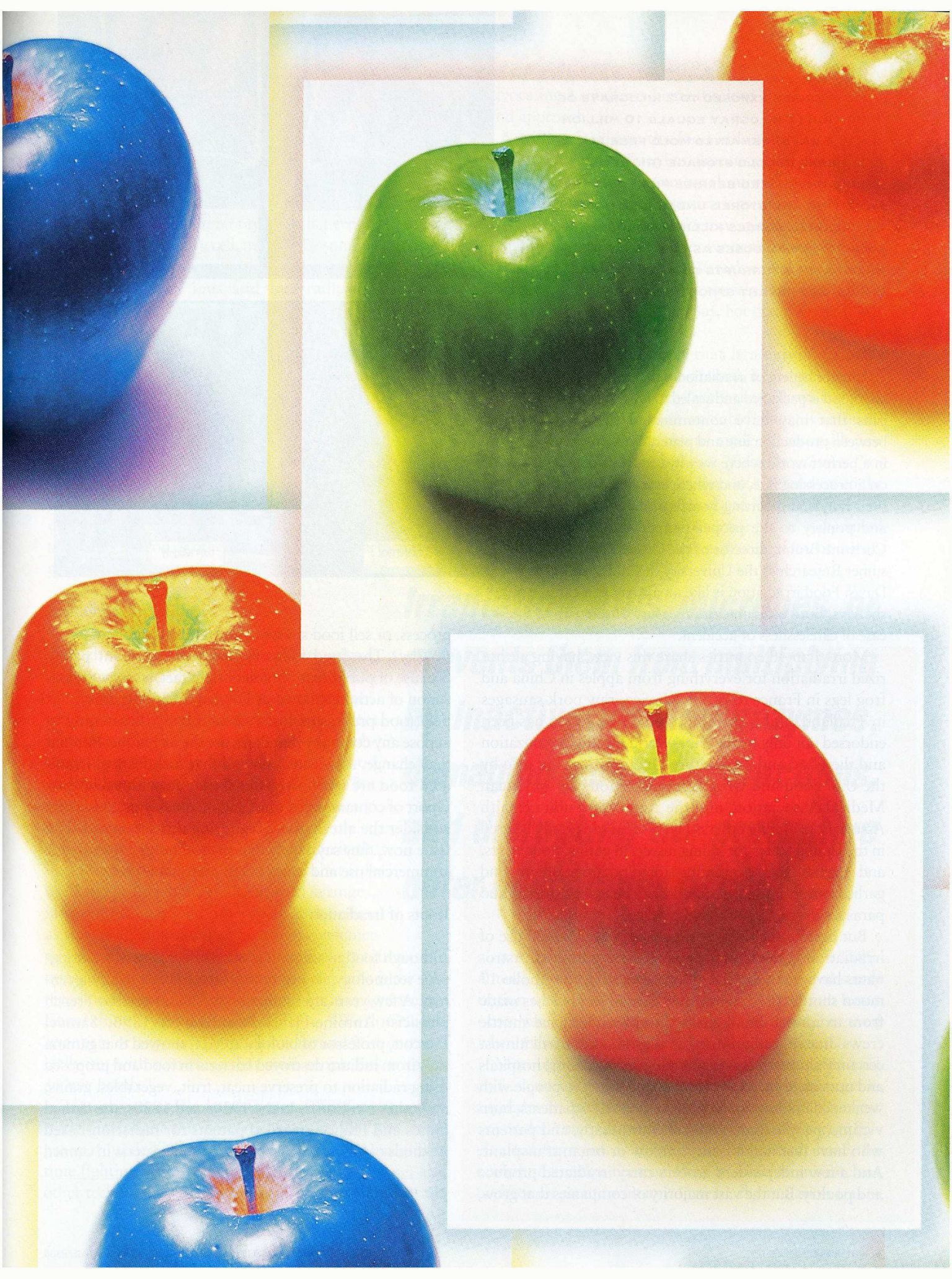
Late this spring, President Clinton gave voice to growing concern by public-health officials over our food supply by calling for "new steps using cutting-edge technology to keep our food safe." One of the technologies that Clinton singles out in his proposed $43 million National Food Safety Initiative is food irradiation, a process that has long been lauded by food-safety experts even as it languishes in the backwaters of research and development. "If the president's program takes hold, food irradiation could get the political push it needs," says James Tillotson, director of the Food Policy Institute at Tufts University.

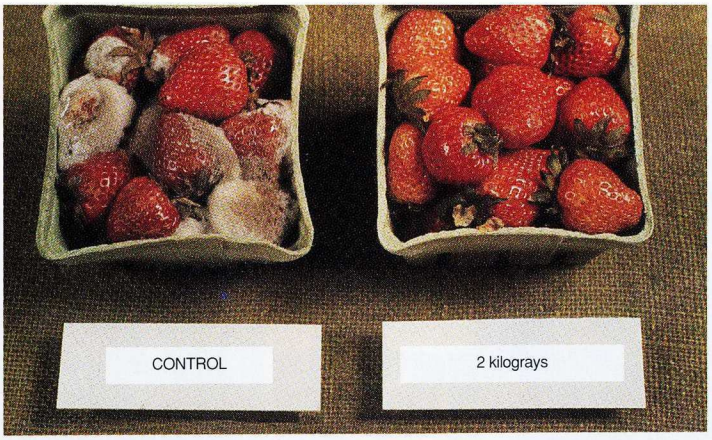
"The benefits of food irradiation are overwhelming," says Richard Lechowich, director of the National Center for Food Safety and Technology at the Illinois Institute of Technology. High-energy radiation kills critters that live in or on food, including the deadly E. coli O157:H7 bacterium and the salmonella and campylobacter species of bacteria found in most uncooked chicken and turkey. "Widespread irradiation of poultry alone in this country could prevent thousands of illnesses and hundreds of deaths every year," concurs Douglas Archer, former deputy director of the Center for Food Safety and Applied Nutrition at the U. S. Food and Drug Administration (FDA).

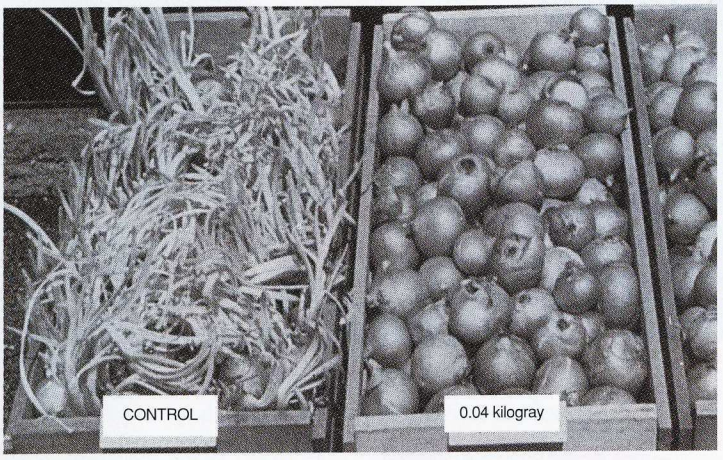


By P.J. Skerrett

Illustration by Harry Bartlett







STRAWBERRIES EXPOSED TO 2 KILOGRAYS OF RADIATION (1 KILOGRAY EQUALS 10 MILLION CHEST X-RAYS) REMAINED MOLD FREE FOR TWO WEEKS IN COLD STORAGE (RIGHT), UNLIKE UNTREATED BERRIES PICKED AT THE SAME TIME AND STORED UNDER IDENTICAL CONDITIONS. BESIDES KILLING MICROBES, IRRADIATION--IN DOSES AS LOW AS 0.04 KILOGRAYS--INTERRUPTS CELL GROWTH IN ONIONS TO PREVENT SPROUTING (BELOW).

A major benefit of irradiation is that it can occur after food is packaged and sealed to kill any organisms that may have contaminated the food between production line and plate. "We don't live in a perfect world where we always detect E. coli on a processing line, and where everyone washes their hands and cutting boards and cooks meat and poultry to the proper temperature," says Christine Bruhn, director of the Center for Consumer Research at the University of California at Davis. Food irradiation is like an air bag in a car, she says. Both offer an extra measure of safety in case of carelessness or accident.

More than 40 countries share this view, having authorized irradiation for everything from apples in China and frog legs in France to rice in Mexico, raw pork sausages in Thailand, and wheat in Canada. Irradiation has been endorsed not only by the U.N. World Health Organization and the Food and Agriculture Organization, but also by the U.S. Food and Drug Administration, the American Medical Association, and the American Public Health Association, among others. The process can legally be used in the United States for killing insects in grains, flour, fruits, and vegetables; for preventing stored potatoes, onions, and garlic from sprouting; and for killing microbes, insects, and parasites in spices, pork, and poultry.

But despite such wide-ranging approval, actual use of irradiation in the United States has been limited. Astronauts have eaten irradiated food ever since the Apollo 17 moon shot in 1972, when they carried sandwiches made from irradiated ham, cheese, and bread. Space shuttle crews dine on radiation-treated food, and it will almost certainly show up on space station menus. Some hospitals and nursing homes serve irradiated chicken to people with weakened immune systems, including AIDS patients, burn victims, people undergoing chemotherapy, and patients who have just had a bone marrow or organ transplant. And a few independent grocers carry irradiated produce and poultry. But the vast majority of companies that grow, process, or sell food shy away from this technology.

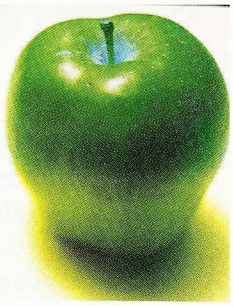
Why? The food industry has been reluctant partly because of public fear of radiation. In fact, a savvy organization of activists known as Food and Water claims it has held food processors in check simply by threatening to expose any company that dares use the technique. But that may change. Advocates contend that such fears of irradiated food are not only groundless but, with each news report of contaminated food, fading quickly as consumers consider the alternative of ignoring this safeguard. The issue now, they say, is whether the technology is ready for commercial use and can work at reasonable cost.

Roots of Irradiation

Although food irradiation is often referred to as a cutting-edge technology, its beginnings stretch back nearly a century. A few years after radiation was discovered by French physicist Antoine-Henri Becquerel in 1896, Samuel Prescott, professor of biology at MIT, showed that gamma rays from radium destroyed bacteria in food and proposed using radiation to preserve meat, fruit, vegetables, grains, and other foodstuffs. In the 1920s and 1930s, the United States and France awarded patents for radiation-based methods of killing parasites in pork and bacteria in canned

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PHOTOS: COUNCIL FOR AGRICULTURAL SCIENCE AND TECHNOLOGY/ EDWARD S. JOSEPHSON



food. Some 25 years of research at MIT and U.S. Army research facilities—from 1943 to 1968—further demonstrated its potential for treating and preserving food.

This high-tech cousin of canning, freezing, and fumigating relies on a simple principle that children of the atomic age know by heart: radiation kills, or at least alters, living cells. When gamma rays or other types of ionizing radiation zip through a cell, they knock some electrons out of their orbits, breaking chemical bonds and leaving behind a trail of ions and free radicals—atoms or molecules with an unpaired electron. These highly reactive substances crash into each other and into their nonirradiated neighbors, creating some new compounds and reforming many that had originally been there.

When a cell is exposed to high enough doses of radiation, the maelstrom of chemical reactions inside an irradiated cell inactivates key enzymes, irreparably damages the cell's genetic instructions, and can disrupt its protective outer membrane. The cell either stops growing and fails to reproduce or dies outright. Either of these outcomes destroys organisms that are natural or introduced contaminants of food or other products or prevents them from multiplying.

Examining the Evidence

Though some foods such as cucumbers, grapes, and some tomatoes turn mushy when radiation breaks cell walls and release enzymes that digest the food and speed up rotting, many others including strawberries, apples, onions, mushrooms, pork, poultry, red meat, and seafood emerge from irradiation intact and edible. But while these foods can legally be irradiated, virtually none of them are.

The problem isn't necessarily radiation itself, because people don't seem to mind that it is used to sterilize half of all sutures, syringes, intravenous lines, and other medical supplies, as well as billions of dollars worth of consumer goods ranging from plastic wrap and milk cartons to tampons and contact lenses. What poses concerns is the juxtaposition of food and irradiation. "Food is a very emotional thing," says Tillotson of Tufts. "We don't want scientists or anyone else mucking around with it, especially not with something that most people link with the atomic bomb."

The activists at Food and Water of Walden, Vt., effectively manipulate this potential reaction. This grassroots group, founded in 1984 to fight hunger, now spends its time fighting food irradiation, genetic engineering, and other technologies used to grow and process food, while advocating a smaller-is-better, back-to-the-land approach.

A willing David to the food industry's Goliath, Food and Water has almost singlehandedly blocked the commercialization of food irradiation. Larger organizations such as Ralph Nader's Public Citizen weigh in on the matter from time to time—"Whenever we need a quote from the big boys," boasts Food and Water's executive director, Michael Colby—but no longer actively campaign against food irradiation because, they say, Food and Water is carrying the ball.

Food and Water charges that irradiation seriously depletes the nutritional value of food, introduces carcinogens, and is essentially a cover-up that allows corporations to sell previously contaminated items. (Curiously, these are identical to the claims made against milk pasteurization early this century—*see "Pasteurization as Prologue," page 33.*) But these charges don't stand up to the evidence or aren't as dire as Food and Water alleges.

It is true that irradiation can alter the nutritional content of food. While no carbohydrates, protein, fats, or minerals are lost, as much as 10 percent of vitamins A, B-1 (thiamine), E, and K can disappear at FDA-approved sterilization doses. But it's also true that similar vitamin losses occur when fresh fruits and vegetables are canned or even when they sit in cold storage.

Irradiation kills microbes or prevents them from multiplying by inactivating key enzymes, damaging genetic instructions, and disrupting the protective outer membranes of cells.

More important, it does not appear that irradiated food causes cancer. First of all, when a hunk of hamburger is zapped with radiation it does not become radioactive, just as you don't start glowing after an x-ray. At the energy levels used for food, ionizing radiation doesn't have the oomph to knock a neutron away from an atom's nucleus or force an atom to fission. Instead, the radiation leaves



behind traces of radiolytic compounds—which merely means broken (lysis) by radiant energy (radio)—that are identical to compounds that naturally occur in the foods we eat every day.

Cancer researcher George Tritsch, now retired from the Roswell Park Cancer Institute in Buffalo, N.Y., and an adviser to Food and Water, points out that some of these radiolytic products are known carcinogens, such as benzene and formaldehyde, and worries that adding more of these products, though measured in parts per billion, will raise cancer rates. This would be a formidable argument if it weren't for the fact that many foods naturally contain much higher levels of these and other cancer-causing agents, says Donald Thayer, research leader for food safety at the U.S. Department of Agriculture's Eastern Regional Research Center. Eggs, for example, contain 100 times more benzene than the highest levels found in food exposed to the maximum doses of sterilizing radiation.

Radiation leaves a trail of known carcinogens—but many foods naturally contain far higher levels of these compounds.

Colby also argues that irradiation may create radiolytic compounds never before identified in food, some of which might cause cancer or other health problems. But he is unable to cite any examples. And, according to Thayer, "in more than 40 years of looking, no one has yet found in foods any compounds unique to the radiation process."

Nor have animal tests turned up any cause for concern. Under the direction of Edward Josephson, professor emeritus of food and nutrition at the University of Rhode Island, researchers at the U.S. Army's Natick (Mass.) laboratories fed irradiated chicken, wheat, oranges, and other foods to four generations of mice, three generations of beagles, and thousands of rats, guinea pigs, and monkeys from the late 1950s to the early 1960s. Even though the radiation doses were 10 to 20 times higher than necessary, he says, the animals eating irradiated foods suffered no more cancer or inherited diseases than animals eating either canned or frozen nonirradiated food.

An inadvertent test of irradiated foods comes from the Paterson Institute for Cancer Research in Manchester, England. For the past 10 years, several thousand mice with impaired immune systems have eaten nothing but radiation-sterilized food. After more than 60 generations, these mice show no more cancers or other diseases than similar mice fed heat-sterilized food.

Finally, the relatively few human studies that have been conducted also suggest that eating irradiated food is safe. In the early 1980s, more than 400 volunteers ate irradiated food for 7 to 15 weeks as part of eight separate studies in China. The volunteers showed no more chromosomal abnormalities—an early warning sign of cancer-causing activity—than those who ate nonirradiated food.

Tougher Testing

Opponents of food irradiation argue that critical tests remain to be done before anyone can say the process is absolutely without risk. Colby argues for standard toxicology tests that would involve irradiating an apple, say, then extracting any radiolytic products that form and feeding those compounds to lab animals at doses hundreds of times higher than that found in irradiated food.

But Josephson, for one, thinks that this exercise is unnecessary. "Why should we feed animals huge doses of these compounds," he says, "when years of animal-feeding studies have already shown that the small amounts that occur in irradiated food don't cause any health or reproductive problems?"

Food and Water adviser Donald Louria, chair of preventive medicine and community health at the University of Medicine and Dentistry of New Jersey, would go one step further than Colby. He says government or industry should fund a study in which volunteers of different ages, races, and socioeconomic backgrounds eat irradiated foods under controlled conditions, and then undergo tests to see if they have higher-than-normal levels of cells with chromosomal abnormalities.

On that score, however, the FDA apparently disagrees. Back in 1958, Congress defined irradiation as an additive rather than a process, even though radiation generates the same sorts of chemical byproducts in food as other processes used to preserve and protect food, including freeze drying, frying, sun drying, and canning. And FDA regulations don't require human studies for food additives, especially when the compounds added are identical to those already found in food, says George Pauli, the FDA's senior food irradiation scientist.

Ironically, neither Food and Water nor any other group

PHOTO: JOHN DILLON

is calling for the FDA to reclassify or restudy other techniques that produce the same byproducts. In fact, until the U.S. Army animal experiments, canned food had never been rigorously tested to see if it caused cancer. "People in the canning industry were holding their breath," recalls Josephson, "hoping we weren't going to find that canned food caused problems compared with irradiated food."



NATURAL-FOOD ACTIVIST MICHAEL COLBY (SHOWN AT FAR RIGHT) AND HIS STAFF AT FOOD AND WATER IN WALDEN, VT., ARGUE THAT IRRADIATION DEPLETES THE NUTRITIONAL VALUE OF FOOD, INTRODUCES CANCER-CAUSING AGENTS, AND IS ESSENTIALLY A COVER UP THAT ALLOWS CORPORATIONS TO SELL PREVIOUSLY CONTAMINATED ITEMS.

Propaganda Campaign

Food and Water's arguments may be shaky, but its public-relations acumen is rock solid, and highly effective. The organization deftly links people's worst fears about radiation to food. For example, one classic Food and Water advertisement shows a mushroom cloud erupting from a freshly cooked hamburger. The message reads: "The Department of Energy has a solution to the problem of radioactive waste. You're going to eat it."

The organization knows how to pressure executives who fear any sort of public controversy. When Food and Water learned that a representative from Hormel Foods attended a 1996 symposium on the benefits of food irradiation, it demanded to know the company's official policy on this technology.

When letters failed, Food and Water sought help from its constituents, which Colby claims total some 100,000, though a recent *Wall Street Journal* article places that figure considerably lower, at around 3,500. Colby asked members of Food and Water's grassroots network to let Hormel know how they felt about irradiation, and supplied preprinted postcards and a listing of Hormel's toll-free phone number.

The organization also ran a full-page ad showing a glowing can of irradiated Spam—one of Hormel's most widely recognized products—in the company's hometown newspaper on the day of its annual stockholder meeting and threatened Hormel officials that it would run the ads nationwide. Copies were sent to 18,000 food-industry executives. Two weeks later, Hormel issued a statement saying that it does not irradiate food. Food and Water sus-

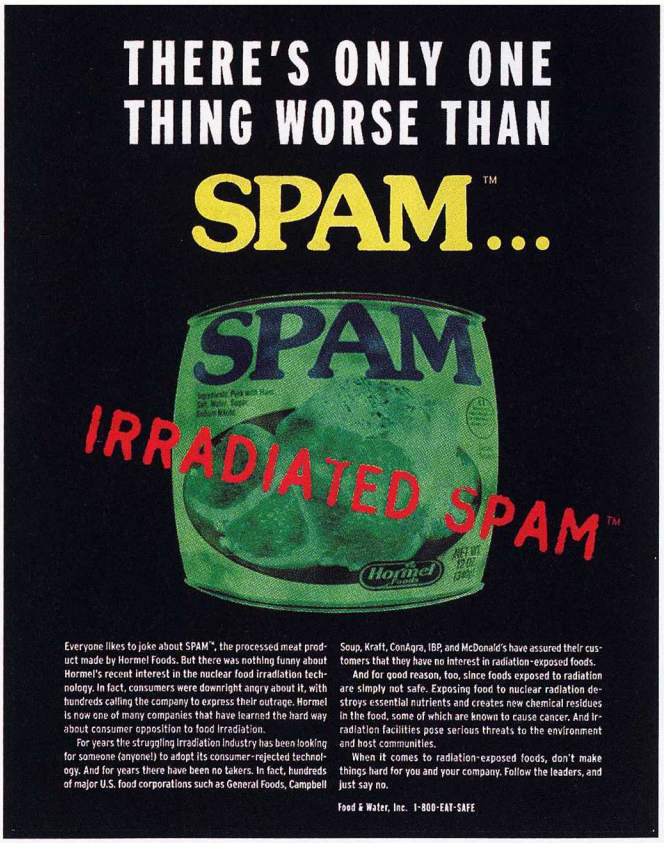
PASTEURIZATION AS PROLOGUE

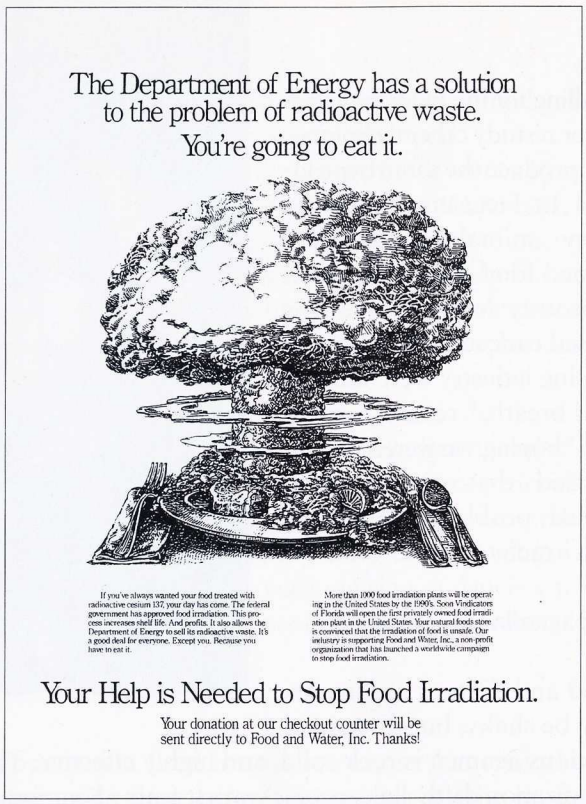
THE controversy over food irradiation bears an uncanny resemblance to the acrimonious debate that raged over milk pasteurization in the early 1900s, when evidence began mounting that raw milk carried microbes, especially those causing tuberculosis. These findings prompted public-health officials, academics, and even some milk producers to call for some sort of treatment. But then as now the proposals were bitterly criticized and tenaciously fought. Here are a few of the anti-pasteurization arguments:

* Pasteurization is little more than an excuse for the sale of contaminated milk and will discourage efforts to produce uncontaminated fresh milk.
* Pasteurization diminishes the nutritional value of milk.
* Pasteurization may lead to the formation of harmful products in milk.
* Pasteurization takes the "life" out of milk.
* Children and invalids thrive better on raw milk than pasteurized milk.
* Pasteurization may be carelessly done, and is not infallible.
* Pasteurization diminishes the fertility of animals fed on it and might lower the human birth rate.

When the Massachusetts state legislature finally approved pasteurization in 1908, it required that pasteurized milk carry the label "Heated Milk" in black, inch-high Gothic letters on a light background.

—P.J. Skerrett





pended the campaign but threatened to resurrect it if Hormel "ever considers using food irradiation in the future."

Colby calls this approach "corporate education" and grassroots activism. Others see it differently. "The organization is shaping the debate and food policy through public fear mongering and scare tactics," says UC Davis's Bruhn.

Technological and Economic Hurdles

Food and Water's anti-irradiation campaign may be the most public obstacle to wider use of food irradiation, but it isn't the only one. "The real barrier is economics and the bottom line" says Martin Stein, president of GrayStar, which is designing a food irradiator that can be installed in existing food-processing plants. In fact, a quick review of the methods the food industry could employ to generate ionizing radiation—using gamma rays from radioactive cobalt-60 or cesium-137, and electron beams or x-rays from linear accelerators—shows that the options have shortcomings that diminish their cost effectiveness, while improved models are still on the drawing board.

✻ *GAMMA RAYS:* Anyone interested in irradiating food today would probably turn to a cobalt-60-based system like the one in Mulberry, Fla., the first commercial facility dedicated to irradiating food. The heart of the plant, established in 1991, is a shiny rack of 400 gamma-ray-emitting cobalt-60 "pencils," each 18 inches long and the diameter of a fat crayon, housed in a chamber surrounded by a concrete wall 6 feet thick. When not in use, the rack is submerged in a 15-foot-deep pool of cooled water that absorbs and neutralizes the gamma rays. At the push of a button, hydraulic arms lift the cobalt rack out of its protective pool and tall metal boxes packed with food slide into the irradiation chamber on an overhead monorail. The boxes follow a zig-zag pattern around the radioactive rack so gamma rays can reach all sides. Treatment times vary—fresh strawberries pass through in 5 to 8 minutes, frozen chicken takes as long as 20 minutes.

Gamma rays from cobalt-60 can penetrate full boxes of fresh or frozen food. But food must be removed from standard shipping pallets, stacked into metal irradiation boxes, and then returned to the pallets when they emerge from the chamber—all extra labor that increases costs.

A new irradiator now under development by GrayStar promises to address this concern by accepting food loaded onto standard pallets, something "everyone in the food industry says is an absolute must," says Stein. The unit will generate gamma rays using cesium-137, which GrayStar would chemically separate from high-level nuclear waste now stored at several power plants around the country.

The prototype machine—which measures 10 feet wide, 8 feet long, and 28 feet high, 12 of which are under-

PHOTO: FOOD & WATER

BY THREATENING TO PUBLISH FULL-PAGE ANTI-IRRADIATION ADVERTISEMENTS (SUCH AS THOSE AT LEFT) WHENEVER INDIVIDUAL FOOD PRODUCERS CONSIDER IRRADIATING THEIR PRODUCTS, ACTIVISTS AT FOOD AND WATER HAVE HELPED BLOCK COMMERCIAL IZATION OF THE MICROBE-KILLING TECHNOLOGY.

ground—is designed to be installed along a meat-packing or food-processing line. After a standard pallet of packaged food rolls into the irradiation chamber, which is constructed from 16-inch steel walls, the operator will seal the doors and instruct a computer to raise the rectangular array of cesium-containing rods from underground for a programmed length of time. Stein is optimistic that the unit will prove attractive to food processors and packers who may be more willing to invest in small, in-house irradiators than build, or contract with, a large central plant to which it must ship food. A working prototype of the compact unit, he says, is still a year away.

❊ *ELECTRON BEAMS AND X-RAYS:* Linear accelerators can generate ionizing radiation for food processing in the form of electron beams. Like a television set, these devices produce electrons from a heated filament sitting inside a vacuum tube. Magnetic fields accelerate the electrons through the tube until they reach energies as high as 10 million electron volts. At the end of the tube, meat or other food is irradiated as it slides by on a conveyor belt. Turn off the juice and the radiation disappears. A linear accelerator delivers more radiation per second than gamma rays, so it may work more quickly than a cobalt- or cesium-based machine.

"The downside is that electrons don't penetrate more than an inch and a half. Thus electron beams would not be able to handle such items as boxes of fruit or sides of beef. However, says Dennis Olson, a professor of food science at Iowa State University who has been testing this method, "you could handle a product up to about three inches thick, something like hamburger or chicken breasts, if you irradiate from both sides." Electron-beam units for such thin food products could move from the lab to the factory within a year or two at today's pace of development, according to Spencer Stevens, president of Omaha-based APA, Inc., an engineering and consulting firm for the food and meat industry.

Olson and others are also exploring the use of x-rays for irradiating food. While it takes even more energy to make x-rays than it does to generate electron beams, thus lowering the efficiency of the process, x-rays have dramatically better penetrating power and could be used on stacked boxes of fresh or frozen food or on slabs of meat.

The Bottom Line

Economics will play a large role in determining which of these approaches, if any, will ever be widely used in food processing. As commodities go, food is cheap, so even slight increases in processing costs can have a big impact on what consumers pay for certain items. Thus, says Stevens, radiation processing can't cost more than a few cents a pound, a figure that in-house irradiators could soon meet.

But the biggest unknown, of course, is whether consumers will buy irradiated food, even if producers can provide it at an affordable price. A series of surveys from the University of California at Davis, the University of Georgia, and Indiana University suggest the public is ready. "When you ask people if they would ever buy irradiated food, 50 to 60 percent say they would," says UC Davis's Bruhn. "When you mention that irradiation can keep food fresh longer and kill bacteria, the percentage rises to 80."



In-store tests and actual sales from a few independent grocery and produce stores offer real-world evidence that consumers might follow through on what they say. For example, Olson and his colleagues at Iowa State University sold irradiated chicken at a grocery store in Manhattan, Kans. Radiation-treated chicken—clearly labeled with a green symbol called a radura that must legally appear on all irradiated food—was displayed next to the traditionally processed store brand. Whichever one was cheaper sold better. Sales split down the middle when both carried the same price tag. Even when the irradiated chicken cost almost 25 cents a pound more, it still accounted for 20 percent of sales, says Olson.

Carrot Top, a produce store in north-suburban Chicago, also has had success selling irradiated food. Owner Jim Corrigan first introduced irradiated strawberries in 1992 with a two-for-one sale, expecting his customers to buy a box of irradiated strawberries and one of nonirradiated strawberries for comparison. Instead, the berries treated with radiation, which killed the molds normally growing on the fruit, outsold untreated berries ten-to-one because they looked better and lasted far longer. Carrot Top has since expanded its irradiated line to include Vidalia onions, blueberries, chicken, exotic Hawaiian fruits, and any other irradiated foods that are available. "I would carry irradiated hamburger today if it



were available, since my customers ask me for it," says Corrigan.

Building Incentives

None of the country's major food companies will publicly acknowledge even a remote interest in food irradiation, yet several developments could push the food industry to adopt irradiation. First, some "traditional" methods for ridding food of pests are under close scrutiny. Methyl bromide, used to fumigate cereal grains, dried fruits and nuts, and fresh fruits and vegetables is scheduled to be banned in the United States as of January 1, 2001. Not only is it toxic to workers—the Environmental Protection Agency classifies it as a Category I acute toxin, the most deadly kind—it also is 50 times more destructive to the ozone layer than chlorine atoms from chlorofluorocarbons. Radiation could offer a reasonable alternative.

It may take an outbreak of food poisoning that results in many deaths before government and the food industry get serious about food irradiation.

Ionizing radiation can also replace ethylene oxide, another widely used toxic fumigant. Radiation kills bacteria and insects more efficiently than the ethylene oxide, says Thomas Mates, general manager of SteriGenics, a California company that owns and operates several medical irradiators. What's more, irradiation doesn't leave behind any residue, and doesn't require any moisture, which can remove some of the volatile chemicals that give spices their smell and taste. SteriGenics recently introduced a line of radiation-treated spices called Purely by Choice.

The changing nature of our food supply may also spur wider use of irradiation. Once upon a time Americans got their food from local growers and neighborhood markets. Today much of our food comes from afar—from across the country and, increasingly, from developing countries. Few of us would eat fruits and vegetables in many of these countries without washing and peeling them. Yet when they are imported and sold in a U.S. store, that concern seems to disappear. "One does not need to leave home to contract traveler's diarrhea caused by an exotic agent," according to a recent editorial in the *New England Journal of Medicine* by Michael Osterholm, head of the Minnesota Department of Health. Food irradiation, he contends, "provides the greatest likelihood of substantially reducing bacterial and parasitic causes of food-borne disease associated with numerous foods, including fresh fruits and vegetables."

Irradiation may get a huge political boost, not to mention funding for further research and development, from the Clinton Administration's food-safety initiative, which is just beginning to wend its way through Congress. Whatever the outcome of the plan, however, the most powerful stimulus for wider use of irradiation is likely to be the ever-larger settlements awarded to people who become sick from eating contaminated food.

A generation ago, individuals felt responsible for the safety of their own food, says Christine Bruhn from UC Davis. Now people blame food growers, processors, and food sellers when they get sick from eating contaminated food, she says. This shift, already seen in million-dollar settlements such as those against Holiday Inn at San Francisco's Fisherman's Wharf and Foodmaster, the parent company of Jack-in-the-Box, is making restaurant owners and grocers take extra steps to make sure the food they deliver or sell is as safe as it can be.

Even though consumers seem willing to buy irradiated food, "it will probably take some truly traumatic E. coli outbreak that causes a number of deaths before government and the food industry get serious about food irradiation," says James Tillotson of Tufts. Without such a crisis, consumers probably wouldn't think of demanding irradiated food and there would be little political push to require leaving companies that explore irradiation open to attack by activist groups such as Food and Water. "No one is willing to get that kind of attention," he says, "even when they might be doing the best thing for consumers." ■



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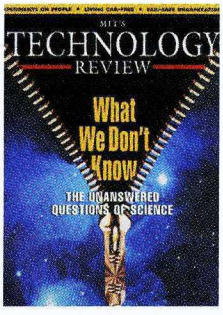
The Great

Unknown

BY ROBERT M. HAZEN

ON HER DEATHBED, ACCORDING TO HER SECRETARY ALICE B. TOKLAS, GERTRUDE STEIN ASKED, "WHAT IS THE ANSWER?" RECEIVING NO REPLY, SHE CONTINUED, "THEN, WHAT IS THE QUESTION?"

Human curiosity, and our insatiable impulse to ask questions, drives scientific research. In the July issue of *Technology Review*, readers had a chance to formulate their own list of the most important unanswered scientific questions. Presented with a list of 14 questions that Carnegie Institution president Maxine Singer and I claimed were among the most important in our book Why Aren't Black Holes Black? The Unanswered Questions at the Frontiers of Science, nearly 200 readers commented on the list by substituting their own favorite questions for ours. ● Most of the respondees agreed with our premise that science, challenged by innumerable fascinating unanswered questions, is far from over. But many readers also identified what



In July, we asked readers to pick today's most profound questions of science. The results, tabulated here, show that while the questions are scientific, the process of identifying them is anything but.

they saw as serious ommisions and a few soundly denounced our list as misguided, elitist, or naive. In short, the survey demonstrated that while scientists are generally convinced that answers are achieved with some degree of objectivity, our choice of questions is highly subjective. Here are what *Technology Review* readers identified as the most compelling questions facing science today.

THE MOST FREQUENTLY ASKED QUESTION

Technology Review readers posed more than 100 different questions, but almost a third of all respondents—by far the largest group—placed questions about the mind, the brain, and the nature of consciousness near the top of their lists. Among the varied questions related to this topic were: How does the mind work? What are emotions? What is love? Can we build a conscious machine? What is the origin of creativity? What do dreams mean? Why do we respond to music?

These questions contrast with our more narrowly focused question: "What are the physical origins of memory?" which one reader described as "almost laughably simple" in comparison with the attempt to understand consciousness. Many of science's deepest thinkers, including Nobel Prize winners Francis Crick and Gerald Edelman, and mathematician Roger Penrose, would agree with *Technology Review* readers that the latter "What is consciousness?" is the most fundamental unanswered question concerning the brain. Crick, who defines consciousness as "attention and short-term memory," has called for an intensified research effort in his book *The Astonishing Hypothesis*.

But the distinction between questions about memory and those about consciousness raises a key point about the nature of science. For a question to be scientific, it must be answerable through a reproducible process of observation, experiment, and theory. Is the study of consciousness, as opposed to the physical brain, scientific? Many researchers, including Stanford computer scientist Terry Winograd and the late physicist Richard Feynman, are not persuaded that it's possible to find a concrete physiological definition of consciousness, much less an unambiguous experimental protocol for its study, any time soon. They contend that since a clear research strategy is lacking, consciousness must for the time being lie outside the domain of science.

Indeed, most unanswered questions about human thought seem to fall somewhere in the nebulous realm between philosophy and science. What is an idea? What is an emotion? What does it mean to be curious or to know something? It's hard to see how these abstract questions can be reduced in any neat way to a collective property of brain tissues, nor is it obvious how to make the giant leap from the concept of thought to a reproducible experiment in the lab.

The problem of consciousness has been pondered by myriad scientists and philosophers, from avowed reductionists who expect that thought and emotion can be explained by neurons alone to skeptics who deny any hope of physical understanding. University of California philosopher David Chalmers adopts a useful intermediate view by dividing the question "What is consciousness?" into what he calls the "easy problem" and the "hard problem."

The AUTHOR'S Questions

In "What We Don't Know" (*see TR July 1997*), Robert Hazen identified 14 questions that he and his colleague Maxine Singer found to be the most important on today's scientific agenda:

1. What is dark matter?
2. What will be the ultimate fate of the universe?
3. Can we devise a theory of everything?
4. How do atoms combine?
5. Will we run out of energy?
6. What's going on inside the earth?
7. How many people can the earth sustain?
8. How did life on earth originate?
9. Can we unravel the genetic code?
10. How did life on earth become so varied?
11. How do we develop from a single cell?
12. What are the physical origins of memory?
13. Is behavior dictated by genes?
14. Are we alone in the universe?

ROBERT M. HAZEN is a research scientist at the Geophysical Laboratory at the Carnegie Institution of Washington, D.C., and is Clarence Robinson professor of earth science at George Mason University. His most recent book is Why Aren't Black Holes Black? The Unanswered Questions at the Frontiers of Science *(Anchor Books), which he coauthored with Maxine Singer, president of the Carnegie Institution and scientist emeritus at the National Institute of Health's Laboratory of Biochemistry.*

The easy problem focuses on mechanics of consciousness: How can humans isolate external stimuli and react to them? How does the brain process information to control behavior? How can we articulate information about our internal state? Neurobiologists have long tackled aspects of these questions, which are amenable to systematic study in much the same way that researchers probe the physical mechanisms of memory. Perhaps, with many decades of intense research, such questions can be answered.

The hard problem, on the other hand, relates to the intangible connections between the physical brain and self-awareness, emotion, perception, and reasoning. How can music evoke a sense of longing, or a poem deep sadness? How does reading a book stimulate curiosity or frustration? What are the physical structures and processes that produce love, fear, melancholy, or greed?

Some researchers believe that, in due time, an understanding of consciousness will follow naturally from research on the physical brain. Others argue for a radically new perspective. Chalmers, for example, makes the startling proposition that consciousness must be accepted as a characteristic of the universe completely distinct from previously recognized physical attributes, such as matter, energy, forces, and motions. Perhaps, he says, consciousness is an (as yet unrecognized) intrinsic property of information.

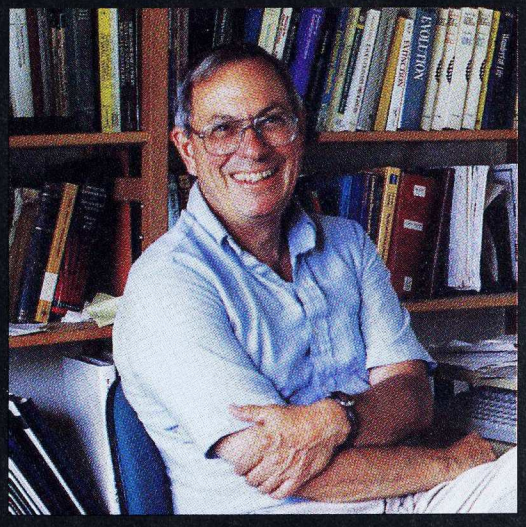
What is consciousness? For the time being, scholars cannot even agree on what exactly the question means, much less imagine the form an answer might take. For as far into the future as anyone cares to foresee, this greatest mystery of the human mind may remain.

Memories are different; they are more tangible and tightly defined. At one level, memories are a kind of information that can be stored, recalled, altered, or deleted—all familiar tasks in the computer age. It's conceivable that each memory is stored in the brain as a molecule or set of molecules that carries a message. Alternatively, memories might be hard-wired into networks of brain cells, or maybe they consist of electrical potentials that pervade the whole brain. Whatever the nature of memories, we can hold out the hope that answers will yield to clever and persistent study.

There's another reason why the quest to understand memory holds a central position in the study of the human brain. Awareness, perception, and thinking depend on receiving information through our senses and analyzing that information in the context of learned patterns of experience—patterns recorded as memories. We cannot be self-aware without a remembered context of existence and personal history. Understanding the physical basis of memories, therefore, is an essential step to knowing what it is to be human—to be conscious of memories.

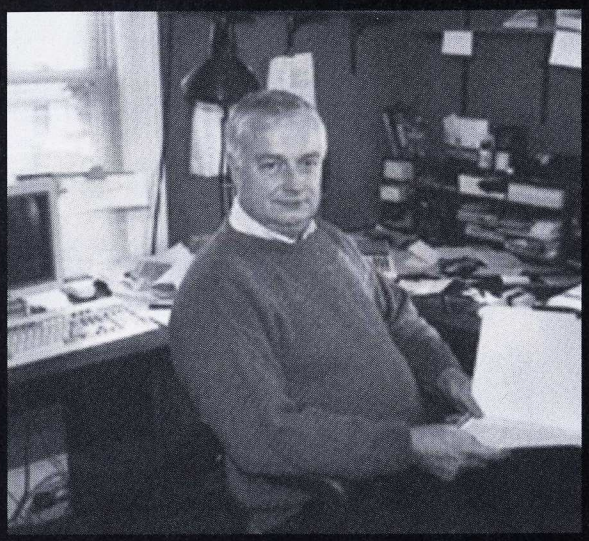


"Since living things are so beautiful, shouldn't there be an underlying mathematics that describes them?"
Thomas D. Schneider
Molecular Information Theorist
National Cancer Institute

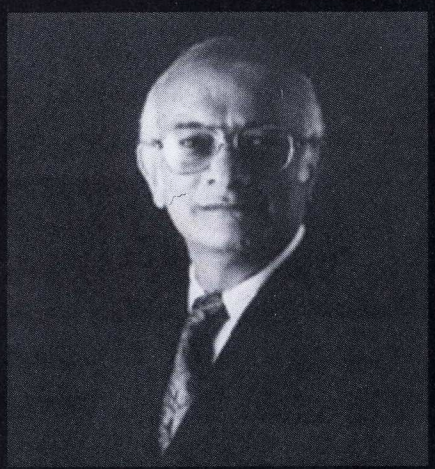


"It seems important to me... to understand the short-term dynamics of solar-type stars. There is considerable evidence that variations in the output of the sun is responsible for wide swings in the earth's climate."
Timothy Fohl
President
Technology Integration Group
Carlisle, Mass.

BOTTOM PHOTO: LINDA ENGLE; ALL OTHER PHOTOS PROVIDED BY READERS QUOTED



"How long will the human race survive? I am most interested in the impact of technology on our survival."
Lauren H. Seiler
Professor of Sociology
The City University of New York



"The most significant science done by humans will, I believe, always be connectable to the human scale, affect human society, in some plausible way. Hazen's questions fail this test."
Rustum Roy
Founding Director
The Materials Research Laboratory
Pennsylvania State University

ONE STEP BEYOND

A number of fascinating questions about the physical design of the universe appeared several times in the survey responses: What is gravity? What is time? What is the connection between the quantum and macroscopic world? What is the relationship between mathematics and the physical world? These are good questions. All are the subject of current research and debate, and any one of them could make a "top 20" list.

But other questions, rather similar in tone and content, are more problematic. Can we develop antigravity? Can we develop time travel? Can matter be transported across space other than physically? Each of these questions postulates technologies that are outside of current physical laws. That's not to say that such technologies are impossible. It's just that science, at present, has no way to address such speculation.

Still other questions approach space and time from a more philosophical perspective: What is the meaning of quantum mechanics? Why is the speed of light what it is, or, why is the speed of light so slow? Why are the fundamental constants what they are? The line between science and philosophy is often fuzzy when we ask why nature behaves the way it does. Scientists can measure the speed of light with exquisite accuracy, but why it has that particular value may defy present theory.

In a similar vein, several readers asked if alternate universes might exist, perhaps with different physical constants. Without specific observations to support or deny these ideas, alternate universes are outside the domain of today's science.

SOCIAL CONCERNS

Quite a few readers condemned us for failing to acknowledge the social sciences. One reader asks, "Where are the big questions with regard to the domain of human [society]?" Another observes, "By focusing on the natural sciences, and completely ignoring the social sciences, both authors neglect to mention the areas of our greatest ignorance: the unanswered questions of sociology, economics, political science, social psychology."

Guilty as charged. Except for our borderline question on behavioral genetics (Is behavior dictated by genes?), we restricted ourselves to the physical and life sciences. A survey similar to ours from the perspective of the social sciences would be fascinating, especially judging from the following questions: Is war inevitable? Can we achieve world peace? How do societies arise? What is the best way to raise a child? What are the relative roles of nature vs. nurture? What is the source of religious impulse? What are the rules of economics? What are the roles of work and leisure time? While

such questions are not on our scientific question list, readers who asked them can take heart that these issues are now in the mainstream of sociological research.

SPECIALIZED KNOWLEDGE

A number of readers' questions seem narrowly focused and specific. For example: What is the nature of turbulence? Why are human females smaller than males? How is the North Pacific High generated? What are the short-term dynamics of solar-type stars? Can we develop synthetic photosynthesis? Can we understand the fundamental principals of catalysts? What causes ice ages? How does a mirror work? What causes ball lightning?

All of these questions are fascinating, but I wouldn't place them anywhere near the top of my own list. Still, determining such rankings is a subjective process that the scientific community faces all the time. Ranking comes most forcefully into play in the day-to-day world in the awarding of prizes and research grants. Academic prizes and the prestige associated with them are usually conferred for work perceived as fundamental and basic. Ernest Rutherford's discovery of the atomic nucleus, Linus Pauling's explanation of the chemical bond, and James Watson and Francis Crick's unraveling of the structure of DNA were all recognized by Nobel Prizes. Prestigious periodicals such as *Science* and *Nature* may only have space for 10 percent of all submissions. Thus, acceptances are based in large measure on the perceived importance of the question being addressed.

Research grants, on the other hand, are usually awarded by government agencies—the Departments of Commerce, Health and Human Services, Defense, and Energy, for example—that have specific pragmatic goals in mind. Many scientists, accordingly, become adept at rationalizing their pursuit of basic research by demonstrating how this research is essential to solving applied problems.

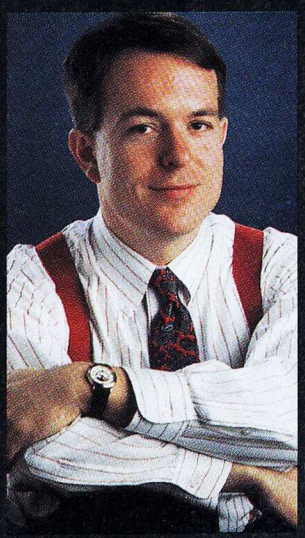
Clearly, the relative importance that we attach to questions is highly subjective. Every culture asks different questions, reflecting their varied beliefs and experiences. All cultures wonder at one time or another about the vast scale of the universe and the ancient origin of life. Not all cultures, however, ask how many stars exist or the exact age of fossil species, much less how these objects evolve. Ultimately, asking the right question at the right time is a key part of the art of doing science.

WAY BEYOND SCIENCE

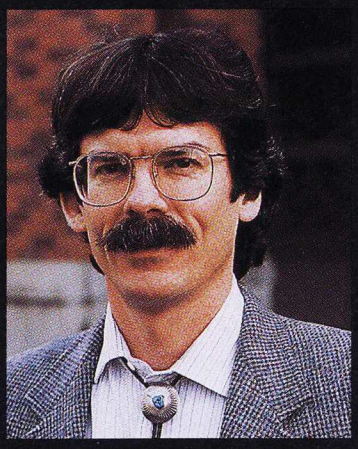
Perhaps the most fascinating of reader responses were the numerous questions that are, by broad consensus, outside the domain of science. A few examples: Is there a god? What happened before the Big Bang? What



"Can matter be transported across space other than physically? Can matter be transported across time?"
Courtland Lewis
Science and Technology Policy Analyst
Melbourne, Fla.

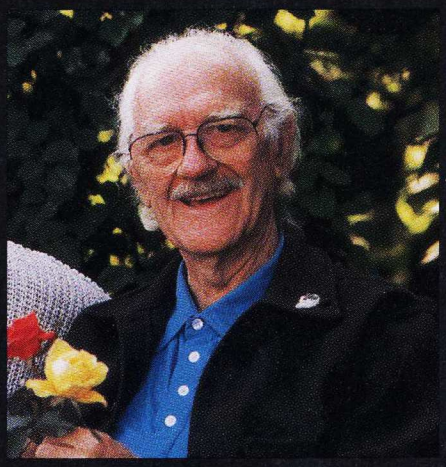


"By focusing on the natural sciences and completely ignoring the social sciences, [Hazen] neglects to mention the areas of our greatest ignorance: the unanswered questions of sociology, economics, political science, social psychology. What are possible forms that societies can take? Why do collective groups form at all? What are the functions of language?
Keith Sawyer
Professor of Education
Washington University



"Why are the principles of quantum mechanics what they are?. . . Precisely why is it that the position and momentum of a particle seem to represent only different aspects of some underlying single thing, rather than two independent properties, as they [do] in classical physics?"

Michael G. Raymer
Director
Oregon Center for Optics
University of Oregon



"One of the things we need to know is how the leaf of a plant makes starch, carbohydrates, sugar, and protein–the process known as photosynthesis."

John H. Pierce
Envirnomental Botonist
Ontario, Canada

happens after death? What is the nature of evil? Is the universe infinite? Are there realms of consciousness or reality that we do not normally perceive?

Science addresses only those questions that can be answered by reproducible observations, controlled experiments, and theory guided by mathematical logic. This distinction between scientific and nonscientitfic inquiry, though sometimes blurred, is neither frivolous nor arbitrary.

Science can reveal if a painting is old, but it cannot determine if the painting is beautiful. It may be used to deduce the origins of the physical universe, but it cannot rationalize why we are here to ponder its existence. Many of the most important questions we face—What is the meaning of life? Whom should I marry? Is there a God?—thus lie outside its domain. Such a realization led economist and philosopher Kenneth Boulding to remark, only partly in jest: "Science is the art of substituting unimportant questions that can be answered for important questions that cannot."

A few questions that lie at the boundaries of science are more difficult to classify. Scientists are divided, for example, regarding questions that several readers proposed regarding extrasensory perception, precognition, numerology, and psychokinesis. While many researchers lump these ideas into the broad category of pseudoscience, reproducible experiments can be performed to test individuals who claim to possess such abilities.

HUMAN NEEDS AND NEW TECHNOLOGIES

Several respondees chastised us for neglecting questions that address pressing human needs. "The most significant science done by humans," according to one reader, "will be connectable to the human scale, affect human society in some plausible way. Hazen's questions fail this test."

Among such questions readers asked are: Can we extend the human life span? Is death inevitable? How can we increase food production? What is earth's global water cycle? Is the earth's ecosystem self-correcting? Can we develop synthetic replacements for the body's organs? What causes weather? Can we direct evolution? Can we build in a process of recovery from the next dark age—assuming there is a next dark age?

Others proposed questions related to developing new technologies: Can we develop new energy technologies? (This was also the basis of our fifth question. Can we develop human space travel? What are limits on computer speed? What will become possible through nanotechnologies?

The difficulty of judging the relative importance of applied questions is well illustrated by efforts to find a

cure for AIDS. Basic discoveries related to viruses, DNA, and the immune system, for example, may not directly benefit anyone now infected with HIV, but eventually they will be essential to finding cures for many diseases, perhaps including AIDS. Discovery of a specific AIDS vaccine, by contrast, might not result in any fundamental new understanding of biological systems, but would have an immediate and profound effect on millions of people. It would seem prudent, therefore, for any AIDS research funding strategy to strike a balance between basic and applied efforts.

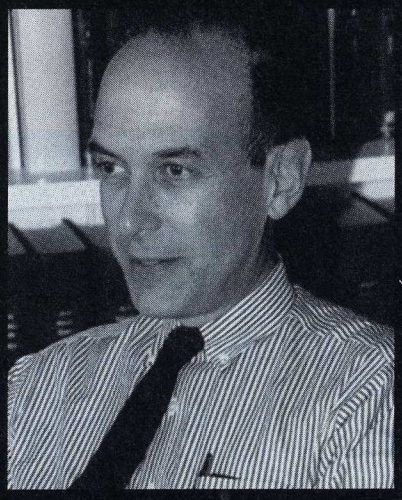
THIS TOO SHALL CHANGE

According to one observant reader, Hazen and Singer's "questions are an oddly unsorted lot that address different levels in an unsystematic way.... The list is too much a creature of our present preoccupations; it is not built to stand the test of time."

We couldn't agree more. The list will change for three reasons. First, scientific questions are inherently answerable, so the questions may, in fact, be answered. Two centuries ago, one of the greatest questions in science was how to achieve a reliable method to determine longitude. A half century ago, the search for the molecular mechanisms of genetics consumed thousands of biologists. Now, new questions arise to replace the old.

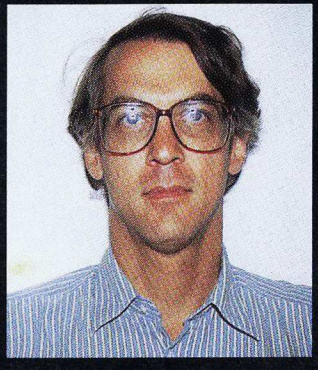
Second, profound questions are not always obvious questions, so new questions may be discovered. While the birth of the universe, the origin of life, and the inevitability of aging and death have invited speculation for thousands of years, other compelling questions, such as the nature of energy, the operation of genes, and the mystery of dark matter, are far more subtle, emerging from the nagging persistence of odd observations and anomalous bits of data. Gradually, over the span of decades or even centuries, we become aware of a fundamental lack in our understanding of the physical world, and a deep mystery—a new question—comes fully to light.

Third, some questions are not now scientific but may be some day. Before Edwin Hubble's discovery of distant galaxies, the question of how the universe began lay outside observational science. Without relevant data, it was a matter of philosophical speculation. But, once astronomers understood what to look for, the origin of the universe entered the mainstream of scientific inquiry. Similarly, "What is time?" and, in my opinion, "What is consciousness?" are today more questions of philosophy than of science, though that situation may change as we learn more about matter, energy, and the brain. And who knows what questions we have not yet thought to ask? But that's the fun part.■



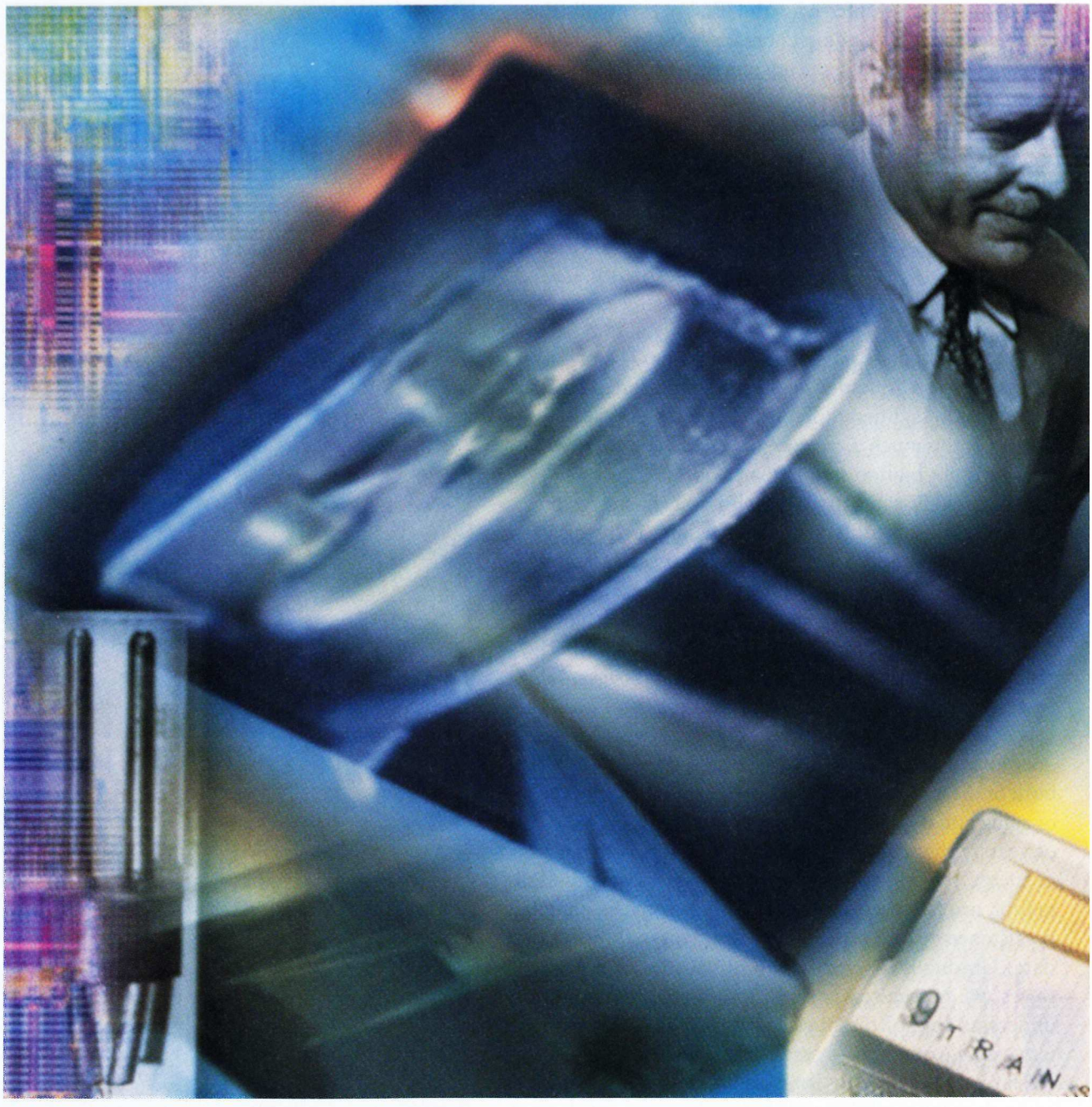
"The great unanswered question in [chemistry] is not the combination of atoms as much as it is the transfer of atoms and molecules that leads to the great chemical processes that constitute both animate and inanimate systems."

Steven J. Lippard
Chair
Department of Chemistry
MIT



"One of the most profoundly hard problems in all of science is that of scene analysis. Imagine creating a computer attached to a camera that could write a description of any scene."

David G. Stork
Chief Scientist
Ricoh Silicon Valley, Inc.
Menlo Park, Calif.



The Incredible Shrinking Transistor

By Michael Riordan



Fifty years ago, researchers at Bell Labs put theory into practice and started a revolution in electronics. Can today's companies foster the same lively interplay between the scientific and the practical?

ILLUSTRATION BY LOGAN SEALE

AT Bell Telephone Laboratories on December 16, 1947, physicists John Bardeen and Walter Brattain attached three flimsy metal contacts to a thin sliver of the element germanium, applied an electric signal, and discovered that the signal emerging from their device was nearly a hundred times stronger than the one that went in. Unveiled a week later to Bell Labs executives, the new solid-state amplifier—soon dubbed a "transistor"—was "a magnificent Christmas present," in the words of research group leader William Shockley,

Today the transistor is little more than an abstract physical principle imprinted innumerable times on narrow slivers of silicon—millions of microscopic ripples on a shimmering crystal sea.

who only a month later conceived an improved version that eventually proved far easier to manufacture.

Fifty years later, transistors have shrunk so dramatically that they are now invisible to the unaided eye. Yet as the crucial ingredients in every microchip, acting as microscopic pumps and valves that regulate the flow of electric current, these minuscule devices continue to have a tremendous impact on almost every aspect of modern life.

It was obvious at the time that Bardeen and Brattain's unwieldy contraption represented a breakthrough in electronics. But its inventors thought of it mainly as a replacement for vacuum tubes, which were used as amplifiers and switches in telephone equipment, radios, and most other electronic devices. Shockley had perhaps the best intuition of what was to come. "There has recently been a great deal of thought spent on electronic brains or computing machines," he speculated in December 1949. "It seems to me that in these robot brains the transistor is the ideal nerve cell."

The physical process Bardeen, Brattain, and Shockley discovered now lies at the throbbing heart of an electronics industry that generates worldwide sales of more than $1 trillion annually. The transistor's greatest value is that it can be so drastically miniaturized: its fundamental operating principles have remained essentially unaltered as its linear dimensions have shrunk more than 10,000-fold. By contrast, vacuum tubes had absolutely no prospects for the kind of astonishing miniaturization that has occurred in solid-state devices. And the tubes' other problems—they were balky, burned out too frequently, generated too much heat, and consumed too much power—proved completely insurmountable.

The first commercial transistors were typically a centimeter long; by the late 1950s, they were measured in millimeters. With the invention of the integrated circuit in 1958, the stage was set for a steady parade of further innovations that reduced the size of transistors to submicron levels—less than a millionth of a meter. Today the transistor is little more than an abstract physical principle imprinted innumerable times on narrow slivers of silicon—millions of microscopic ripples on a shimmering crystal sea. As Intel's cofounder Gordon Moore recently noted, there are more transistors made every year than raindrops falling on California, and producing one costs less than printing a single character in a newspaper.

"The synergy between a new component and a new application generated an explosive growth of both," observed Moore's longtime partner Robert Noyce, reflecting on how the transistor and computer grew up together. He made this comment in 1977, a few years before the personal computer began to stimulate yet another commercial explosion based on semiconductors. More than any other factor, the fantastic shrinkage of the transistor in both size and cost is what has allowed the average person to own and operate a computer that is far more powerful than anything the armed services or major corporations could afford a few decades ago. If we had instead had to rely on vacuum tubes, for example, the computing power of a Pentium chip would require a machine as big as the Pentagon.

And just this past year—which also happens to be the centennial of the electron's discovery—there have been successful attempts to build transistors so small that they involve the transmission of only one electron through a channel less than 10 nanometers long. If this technology can ever be transferred to the production line, another hundredfold reduction in the size of transistors may be in the offing.

MICHAEL RIORDAN is assistant to the director at the Stanford Linear Accelerator Center and a physicist at the University of California, Santa Cruz. He is author of The Hunting of the Quark *and coauthor with Lillian Hoddeson of the recently published* Crystal Fire: The Birth of the Information Age *(W. W. Norton), a detailed account of the scientific origins of the transistor and microchip from which some of the material in this article has been derived.*



John Bardeen, William Shockley, and Walter Brattain (above left) shared the 1956 Nobel Prize in physics for the invention of the transistor. Initially conceived as an alternative to vacuum tubes (shown on either side of transistor, above right) this device paved the way for the computer revolution—a role only Shockley even vaguely anticipated.

Rare Combinations

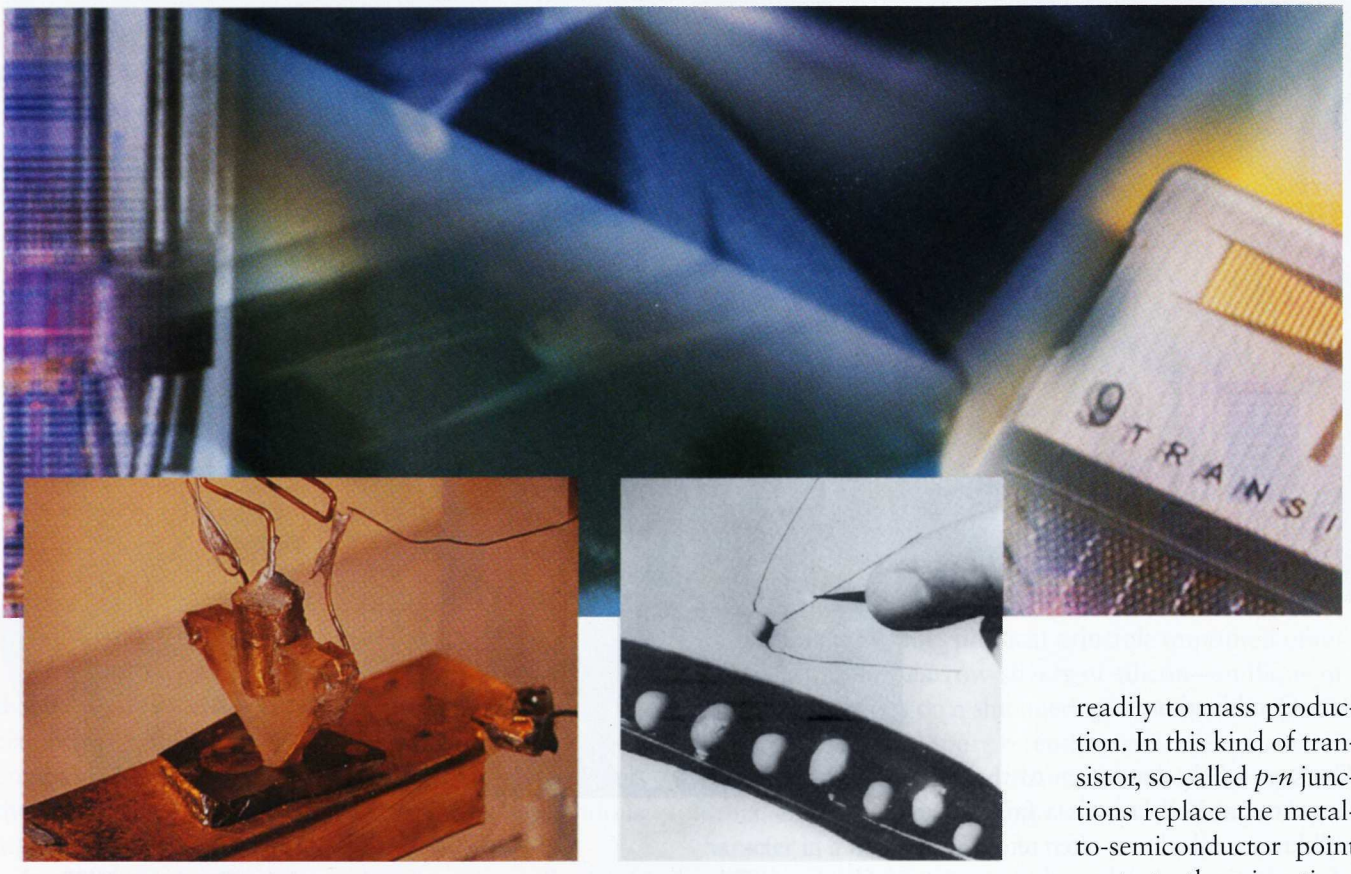
The saga of the invention of the transistor at Bell Labs is a fairly well-known tale that is often retold when questions arise about the importance of basic research in the innovation process. Much less familiar is the story of technology development that ensued. It was this rare combination of basic research *and* fundamental technology development that made modern transistors and microchips possible. Few, if any, episodes in the history of innovation can compare.

The Labs combined a pragmatic, goal-oriented research philosophy with what Shockley called "respect for the scientific aspects of practical problems." Research was guided by the long-range goal of improving the components and services of the Bell System—better switches, clearer signals, etc. But within that context, scientists had ample freedom to do basic research on the properties of materials. Leading theoretical physicists worked shoulder to shoulder with first-rate experimenters and some of the best device-development engineers in the country. The invention and development of the transistor illustrates this interplay between the practical and the scientific that characterized Bell Labs in its heyday.

When Shockley's original ideas for making a solid-state amplifier failed, for example, Bardeen proposed an entirely different theory of semiconductor behavior that he eventually published in the *Physical Review.* Shockley's "field effect" approach involved the use of external electric fields to induce an excess of electrons near the surface of crystalline materials such as silicon; with more electrons congregating there, more current should flow. Or so he thought. To account for the apparent lack of any such effect, Bardeen proposed his theory of "surface states," in which electrons become trapped on the surface and block electric fields from penetrating. This was a brand new starting point that reoriented the group's research efforts toward understanding these troublesome states. "We abandoned the attempt to make an amplifying device," recalled Shockley, "and concentrated on new experiments related to Bardeen's surface states."

When Brattain stumbled upon a crude way to overcome this blockage in November 1947, however, the group's attention returned almost immediately to the practical goal of making a solid-state amplifier. A month later they invented the first transistor, the point-contact transistor, which had two strips of gold foil glued to the sides of a plastic wedge that pressed the foil edges into a germanium slab. Although this weird gizmo stretched nearly an inch, the novel physical process responsible for power gain

PHOTOS: UPI/CORBIS-BETTMANN/AT&T ARCHIVES



The inch-long point-contact transistor (above left) invented in December 1947 was poorly suited for commercial use. It soon gave way to the pea-sized junction transistor (above right), pioneered by William Shockley and fabricated in 1951. Much simpler and more rugged than the earlier version, the junction transistor was more easily adapted to mass production.

occurred in a mere 2 mils—or 50 microns, about the thickness of a sheet of paper—of germanium between the metal points touching its surface. Positively charged quantum-mechanical entities known as "holes" generated beneath one point trickled along a surface layer to the other point, reducing the resistance of the material beneath it and thereby enhancing the current flowing through it.

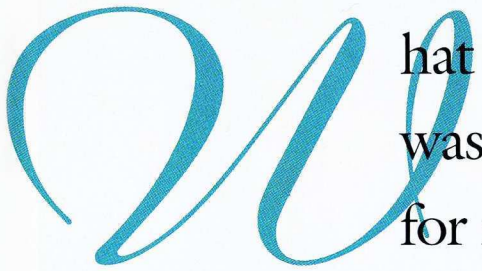
Under the enlightened management of Mervin Kelly and Jack Morton, Bell Labs soon began to pour resources into developing technologies to make transistors commercially viable. It perfected methods of purifying germanium and silicon, and growing large crystals of these elements. Within a few years, these technologies permitted Shockley and colleagues to realize his idea of a junction transistor, which proved far more reliable than Bardeen and Brattain's odd device and lent itself much more readily to mass production. In this kind of transistor, so-called *p-n* junctions replace the metal-to-semiconductor point contacts; these junctions are formed between two dissimilar layers of semiconductor material impregnated with different impurities to induce a slight excess of electrons or holes. This approach proved to be crucial in manufacturing the cheap, reliable transistors that began appearing in electrical devices such as radios and hearing aids during the 1950s.

What's more, the Labs made these and other technologies readily available to firms that were eager to get into the semiconductor business. Combining them with a few additional innovations of their own, Noyce and Jack Kilby invented the integrated circuit at Fairchild Semiconductor and Texas Instruments toward the end of the decade. Better known today as microchips, which now incorporate millions of transistors on a single sliver of silicon, these circuits form the basis of today's $150 billion semiconductor industry. As Morton observed, "Sometimes when you spread your bread on water, it comes back as angel's food cake."

Further Evolution

Fifty years of materials science and engineering have collapsed the dimensions needed for the transistor effect to the submicron level. Germanium has been replaced by silicon, which behaves far better at high temperatures. Diffusion of micron-deep layers of impurity atoms into silicon and formation of a glassy, protective oxide layer upon it, pho-

PHOTOS: AT&T ARCHIVES



What characterized postwar Bell Labs was that the full array of talents necessary for revolutionary innovation was to be found under a single roof.

tolithography for etching delicate features on the silicon surface, and vapor deposition of metal contacts on top of this glassy layer began to allow mass production of integrated circuits containing many transistors and other solid-state components.

Once Bell Labs finally brought Bardeen's surface states under control in 1960, by formation of the oxide layer in a carefully controlled environment, Shockley's original field-effect approach returned to the fore in the form of the metal-oxide-semiconductor (MOS) transistors that dominate the industry today. Here an electric field is applied through the insulating oxide layer by charging a tiny strip of metal deposited on its surface; this field governs the current flowing in the silicon just beneath. Small changes in the electric charge on the strip can have a huge impact on this current—sometimes even blocking it entirely.

In 1965 Moore observed that the number of individual components on integrated circuits was doubling every year. He extrapolated this exponential growth for another decade and came up with an astounding projection: that the circuits of 1975 would contain some 65,000 devices. Now enshrined as Moore's Law, his prediction has continued to hold true for over three decades, though the doubling period has grown to about 18 months. The most advanced chips today contain millions of transistors—each with typical dimensions of less than half a micron. And photolithography techniques based on ultraviolet light promise a further size reduction to nearly a tenth of a micron, or 100 nanometers. Chips with billions of solid-state components may soon become a reality.

Innovation Today

The crucial lesson to learn from the transistor episode is that basic research within the confines of a profit-motivated company led to a completely new and phenomenally valuable starting point for electronics. A close interplay between the practical and the scientific led to the discovery and rapid development of the physical process of transistor action, which could be so drastically miniaturized.

But postwar Bell Labs was a unique institution that would be very difficult—if not impossible—to replicate today. What Kelly described as an "institute of creative technology," it concentrated the intellectual energies of half a dozen eventual Nobel laureates under the roof of a single industrial laboratory in New Jersey. However its parent firm, AT&T, was in a very special situation: it held a monopoly on telephone service throughout the United States. Therefore every time anyone placed a long-distance phone call, she was in effect paying a basic research and technology development tax to support the ongoing projects at the Labs. In return, many of the scientists and engineers working there considered themselves part of a "national resource" that had a responsibility to serve the national interest.

In today's highly competitive business climate, most companies cannot afford research and development expenses that are unlikely to improve their profitability for years. Driven by profit pressures and 18-month product cycles, few corporations can afford to put together the multidisciplinary teams and allow them the broad research latitude that Bell Labs did with its solid-state group in the postwar years. And making their new technologies so freely available is absolutely unthinkable.

The federal government tries to help bridge the gap between science and industry by promoting technology transfer and advanced technology programs. But these are difficult propositions, fraught with severe problems and political disagreements. In today's fragmented R&D environment, physicists at research universities and national laboratories continue to pursue imagined superstrings and leptoquarks that have no conceivable practical applications; meanwhile engineers at semiconductor firms focus on developing ways to etch ever finer features on silicon.

Partially because of this unfortunate dichotomy, innovations have difficulty reaching production. Recent breakthroughs such as fullerene nanostructures and high-temperature superconductors remain laboratory curiosities; compared to the transistor, which began to appear in hearing aids hardly five years after it was invented, these inno-



The first integrated circuit (above left), developed by Jack Kilby at Texas Instruments in 1958, consisted of a series of germanium components connected by gold wire and mounted on one side of a germanium chip nearly half an inch long. Today, Intel's Pentium Pro microprocessor chip, shown above right at actual size, contains 5.5 million transistors.

vations are limping toward commercialization. A possible solution may lie within industry consortia—such as Austin's Sematech—that are aimed principally at developing the deep pools of new technology their participating firms need to improve product lines. Basic research groups might be incorporated within such well-funded consortia. That way they would operate in the midst of a pragmatic environment that could also promote the fundamental development usually needed to turn scientific discoveries into useful products.

Another hopeful trend is that major companies such as Microsoft that have a comfortable share of—or a virtual monopoly on—their specific market are once again beginning to see the wisdom of investing in research. This is what occurred at Xerox's Palo Alto Research Center during the 1970s and led to the development of such extremely useful information technologies as Ethernet, the mouse, and the graphical user interface. Under the leadership of Bill Gates and Nathan Myhrvold, Microsoft has recently taken a similar turn, devoting hundreds of millions to basic research and development projects in computer science. But I wonder just how much the firm will share its findings with other companies.

Whatever the case, it is important to recognize the true partnership that must exist between science and technology. "It's not science becomes technology becomes products," claims Moore in attacking the Bell Labs "linear model" of industrial development. "It's technology that gets the science to come along behind it." But the "science" he refers to is the narrowly applied science done in most of industry today—from which few, if any, radically new innovations and points of departure will ever emerge. Science and technology are like the two intertwined polypeptide chains in a DNA molecule. Each influences the other in a complicated, symbiotic relationship that would be greatly diminished if either one became the other's handmaiden.

My central point is that we need to overcome the fragmented nature of today's R&D enterprise. What characterized postwar Bell Labs and led to the invention and development of the transistor was that the *full array* of talents necessary for revolutionary innovation was to be found under a single roof, working closely together as a well-oiled unit under an enlightened management that understood how such multidisciplinary teams had developed radar and the atomic bomb during World War II. I hope that we will not need another such cataclysm to remind us once again of the value of cooperative research and development.■



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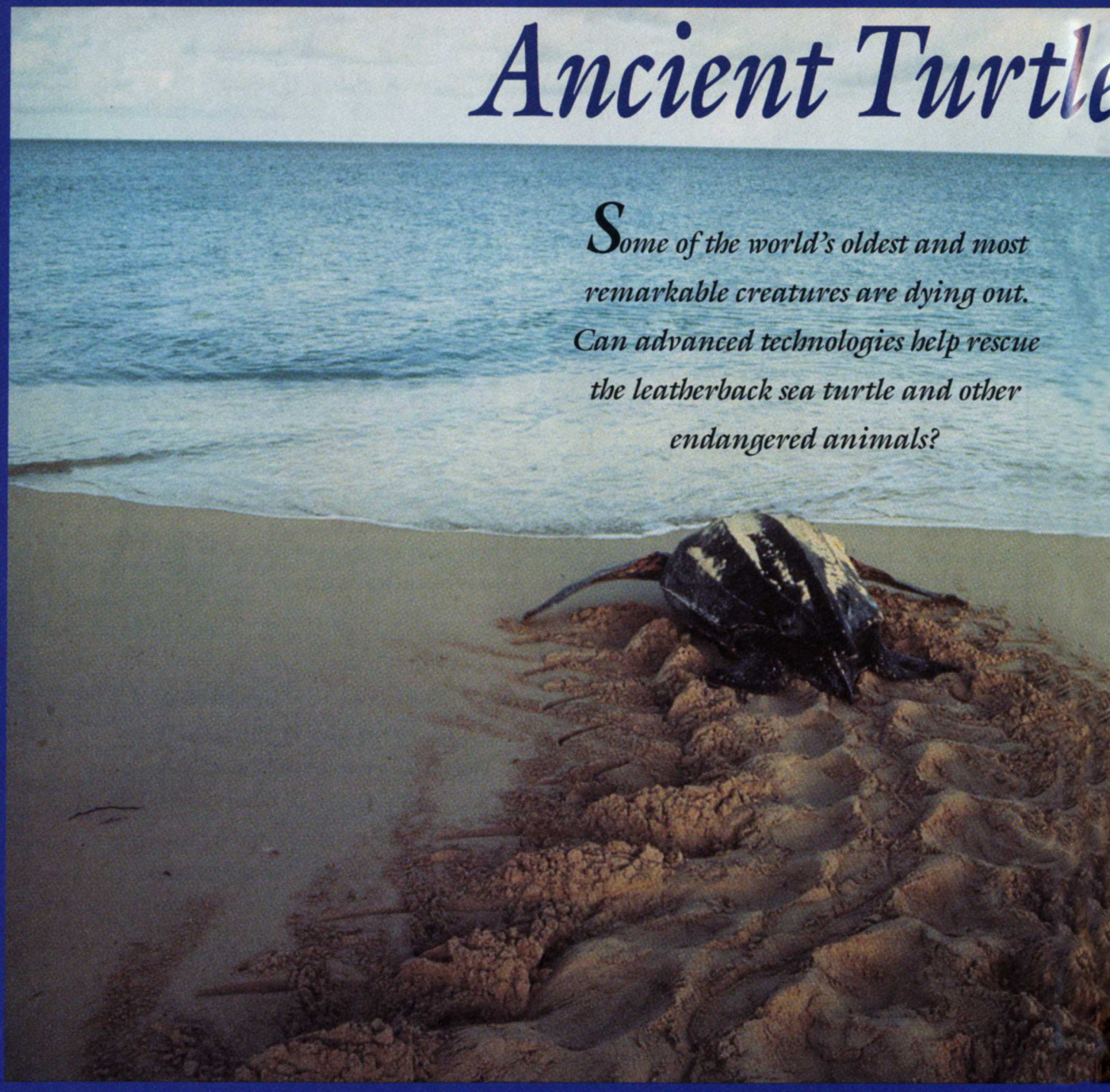
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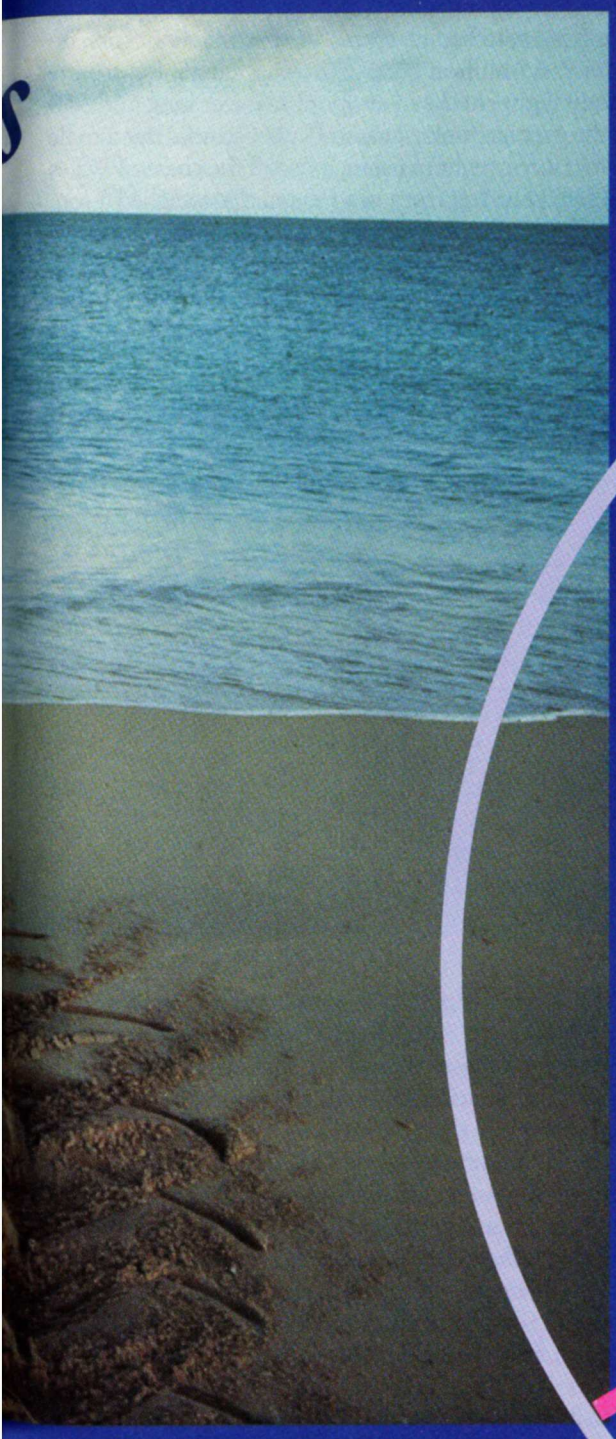
Ancient Turtle



Some of the world's oldest and most remarkable creatures are dying out. Can advanced technologies help rescue the leatherback sea turtle and other endangered animals?

By Peter Tyson

FOR



I'm kneeling on a sandy beach in Costa Rica on a balmy January night helping biologists administer an ultrasound to a leatherback sea turtle. They are hoping to learn more about her reproductive cycle, to better protect populations of this endangered reptile at its nesting beaches around the world. The turtle has come ashore to lay her eggs, as her kind have done since dinosaurs roamed the earth. I watched as she hauled her enormous bulk up the beach, pivoted slowly around to face the ocean, and began scooping out an oval pit in the sand with her hind flippers.

PHOTO BY SCOTT A. ECKERT

She soon entered her egg-laying trance, a quiescent state in which she remains for an hour until she covers over her nest and heads back to the surf.

In her reverie, she takes no notice of us as we get to work. We unpack the equipment, which looks like a desktop computer, and set it down in the sand just behind her. A switch is thrown, and flickering light from the screen lights up the turtle's hind end. Two of us, one on each side, hold down her huge front flippers to ensure that she doesn't start flinging sand in our faces when she begins concealing her nest. Those oarlike flippers can toss any one of us aside like so much flotsam, but they lie idle at her sides. I feel for her in her labor. Her weight makes it difficult for her to breath, and she sucks in air in great gasps. Tears designed to carry away excess salt dribble like saliva from her eyes, making her look as if she is crying from the strain.

We wait while she drops about 100 moist, white eggs into the nest. When she is finished, David Rostal, a biologist at Georgia Southern University, carefully moves the ultrasound probe across her skin over her uterus. Though I am familiar with ultrasounds, having watched the development of my own two babies, I cannot decipher the picture that forms on the screen. To Rostal, however, it reveals whether she has mature ovaries bearing preovulatory vitellogenic follicles—that is, whether she will return later in the season to lay another batch of eggs.

Notwithstanding my familiarity with ultrasounds, I find it truly incongruous to witness one of the most modern of medical tests being used on one of the most ancient of animals. Yet such scenes are becoming increasingly common. Today, on lonely mountaintops, in remote stretches of rainforest, and far out in the oceans, scientists are turning to all manner of high-tech tools to help them study threatened wildlife. Techniques range from tracing family trees of endangered species by analyzing their DNA to using video cameras strapped to sperm whales to film giant squid in their natural environment. In many cases, these advanced technologies are allowing scientists to investigate aspects of ecology, physiology, and behavior that they were never able to investigate before. And by enabling researchers and wildlife managers to identify crucial missing links in animal life cycles, the techniques are bettering endangered species' chances for survival.

The work taking place with leatherbacks on this beach—Playa Grande on Costa Rica's Pacific coast—is a case in point. For on that half-mile-long stretch of sand, biologists are making use of perhaps more high-tech gadgets than any other biologists working on any other animal. And with these tools they are answering a sea of previously unanswerable questions about the turtles—and so learning how remarkable they are and what kinds of conservation measures may help them.

PETER TYSON is a contributing writer for Technology Review *and a senior editor at* Earthwatch *magazine.*

THE LEATHERY TURTLE

Dermochelys coriacea, "the turtle covered in leathery skin," is unique among sea turtles, which also include the loggerheads, greens, hawksbills, and ridleys. It is the most ancient living reptile, around in its current form for at least 20 million years and possibly over 100 million years. It is also the biggest, having watched its rivals for size, the dinosaurs, go extinct some 65 million years ago. The female before me this tranquil night checks in at about five feet long and 550 pounds, the average for nesters on Playa Grande. But a male leatherback once caught in fishing nets off the coast of Wales stretched fully nine feet from head to tail and weighed a ton.

Despite their bulk, leatherbacks migrate farther and dive deeper than any other reptile—indeed, than almost any other animal. After nesting in the tropics, the giant turtles typically swim thousands of miles to reach their favorite feeding grounds in subpolar waters. Along the way, they regularly dive more than 3,000 feet straight down, in search of food or to escape the rare predator such as a killer whale. Their streamlined black body, with its smooth, leathery skin and ridged, highly tapered carapace—which lends the species the popular names of "keelback" and "trunkback"—eases long-distance swimming. A collapsible body frame that includes a high cartilage-to-bone ratio and few fused ribs (even their shell is as flexible as an eraser) allows leatherbacks to deal with the pressure, which at 3,000 feet approaches 1,500 pounds per square inch. Astonishingly, they manage all these feats on a diet of nothing more than jellyfish.


a.

Despite its uniqueness, the leatherback is on the road to extinction. Frank Paladino, a biologist at Indiana-Purdue University at Fort Wayne who has run the project at Playa Grande since 1988 with James Spotila of Drexel University, recently estimated that the global population has dropped by two-thirds since 1980 alone, from 115,000 to 34,500

PHOTOS: SCOTT A. ECKERT & PETER TYSON

nesting females. (Censusing males is impossible, as they never come ashore and are rarely observed in the open ocean.)

Though the leatherback spends most of its life far out to sea, its chief threats, ironically, lie ashore. Laying its eggs on land is the one trait it has retained from its earliest ancestors, the land-dwelling tortoises, and that trait has now come back to haunt it. On leatherback nesting beaches throughout the tropical world, people raid the turtle's nests for their delectable eggs, build over their habitat with houses and hotels, and occasionally kill nesting females for their meat. Increasingly, though, leatherbacks are also losing their lives on the high seas, where fishermen harpoon them for food or for the thick, yellow oil contained in their flesh. (The oil is used in the Caribbean as an aphrodisiac or as a chest rub to relieve congestion and by fishermen in Arabia and India as a treatment for boat timbers.) The turtles also perish at sea when longline fishing gear unintentionally snags and drowns them, and floating plastic garbage chokes them when they mistake it for jellyfish.

To slow or even reverse this precipitous decline, biologists are rushing to better understand the species. "We desperately need to know where these animals go in the open ocean and what they do out there," says Scott Eckert of the Hubbs-Sea World Research Institute in San Diego, Calif.

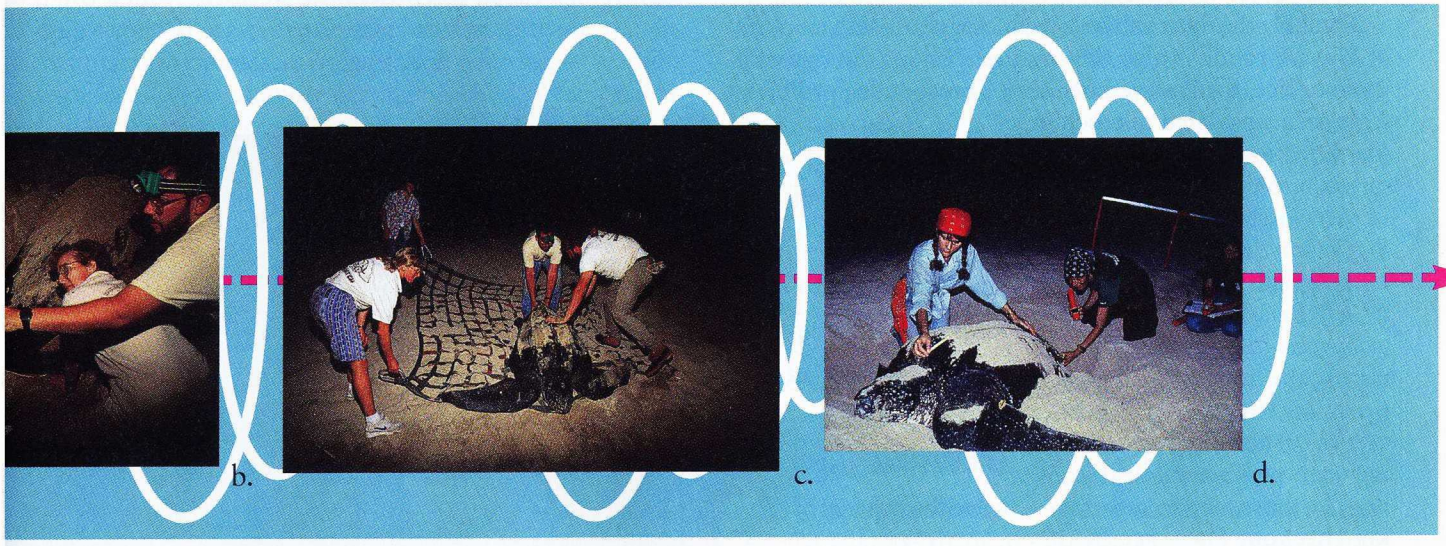
Biologists have no idea where the turtles, which depart their natal beaches as two-ounce hatchlings, spend their developmental years. Nor do they know how fast they grow, at what age they reach sexual maturity, or how long they live. They're not sure how females find their way to feeding grounds, or how they find their way back to their favorite nesting beaches. No one has *ever* reported seeing leatherbacks mate. "When you realize those very basic pieces of information are missing, you realize why we're having such a struggle trying to save these creatures," says Eckert, who says he has begun to fear, for the first time in 15 years in the field, that their extinction may occur in his lifetime.

TURNING TO TECHNOLOGY

When we finish with the ultrasound, we all step back and watch the turtle cover over her nest. Her giant front flippers send shovelfuls of sand flying behind her, and within minutes I can only guess where the nest actually lies. Leatherbacks must take special care to conceal their eggs, as many non-human predators—from mongooses to dogs—also dig them up. Soon she finishes her work and begins dragging herself down the berm toward the breaking waves.

But we are not through with her yet. Rostal wants to take a blood sample, to see if there is a correlation between her testosterone levels and the presence of those preovulatory follicles. The goal is to discover what triggers a female to lay her eggs and, when she's done, to leave the region for the season. By better understanding the egg-laying cycle, conservationists can know not only where but more precisely when to extend protection to nesting females.

No longer in her trance, the leatherback is now hellbent on reaching the water and will not sit still while we try to draw her blood. So we lay down a tarp of thick rubber webbing in her path. When she crawls onto it, we take up the four corners and, after several attempts, succeed in pinning her powerful flippers at her side. Rostal wastes no time in getting the sample, which he extracts from her neck with a long hypodermic needle. Along with samples from other turtles, the blood later reveals that



Researchers soon hope to inject microchips into hatchlings (a) to identify turtles when they return to nest. Scientists examine nesting females--by taking ultrasound tests of their ovaries (b), blood samples (c), and measurements (d)--to understand the species' egg-laying cycles and determine when to protect its shoreline habitat.

females bearing mature ovaries with multiple large follicles, such as our turtle that night, do show high testosterone levels, while those with depleted ovaries have correspondingly low levels of the hormone. Such clues to the timing and mechanics of reproduction will help scientists better monitor discrete leatherback populations across the tropics, from Mexico to Malaysia.

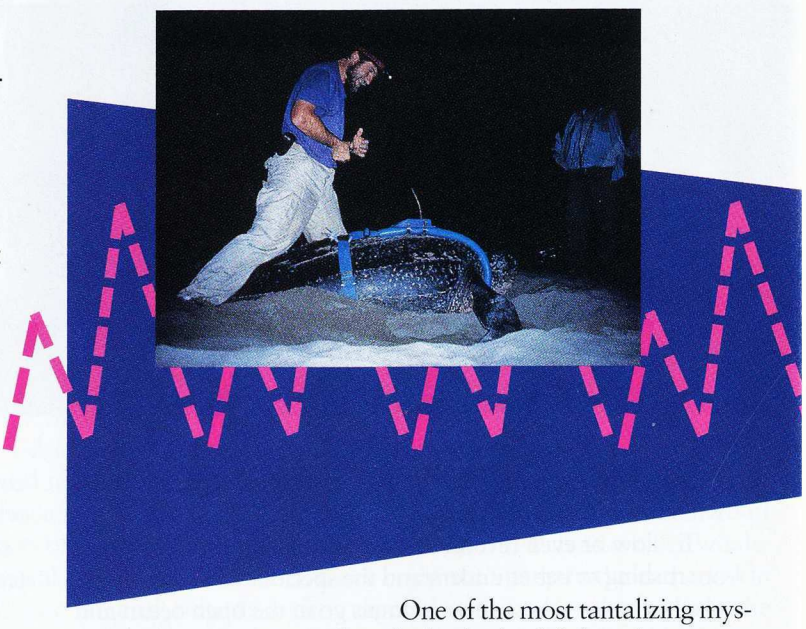
As sophisticated as the blood and ultrasound testing are, they represent just the tip of the proverbial iceberg for Paladino and other leatherback researchers. In their efforts to gather as much information as they can about each turtle, nest, egg, and hatchling on Playa Grande and elsewhere, they rely on a wide range of techniques. Certain methods remain low-tech, such as recording each mother's carapace length and width with a measuring tape (to determine average sizes of nesters there) and marking the exact location of each nest with a wooden stake (to learn what makes an ideal nesting site). But other methods rely on some of the most advanced technologies available.

Arguably the most valuable technology Paladino employs at Playa Grande is also the smallest. About the size of a grain of rice, the Passive Integrated Transponder, or PIT, is a glass-encapsulated microchip identification tag that his team injects into the shoulder muscle of every nester that crawls onto Playa Grande. PIT tags are more reliable than metal flipper tags, which Paladino uses as well, even though they often fall off during the animal's peregrinations at sea. As each turtle comes ashore, project staff members pass a hand-held scanner, like those used in supermarket checkout lines, across the reptile's shoulder to read the I.D. code.

By identifying individuals, researchers can answer a bevy of questions. Over the years, Paladino and his colleagues have proven, for instance, that Playa Grande—which at its height in the late 1980s saw about 1,600 nesters a season—is one of the largest leatherback nesting colonies in the Pacific Ocean. They have also shown that females tend to lay eggs, on average, five times during the October-to-February nesting season. This finding may have conservation implications. For example, if females hang around relatively close to the beach, boating and fishing near nesting beaches may need to be restricted during these months.

Paladino now hopes to begin implanting PIT tags into newborns. Though he fears that as hatchlings grow, the tags may become so buried in dense tissue that they become unreadable, he hopes enough will remain viable sufficiently long to help clear up such enigmas as how fast leatherbacks mature. For instance, if a tagged newborn female returns as an adult to its natal beach to lay eggs—as many researchers believe leatherbacks do—then, with a quick read of the tag, the scientists can know just how old that turtle is and how long it took to reach sexual maturity.

Other technologies that come into play on shore shed light on leatherback physiology. As each turtle on Playa Grande lays her eggs, Paladino's crews place the wires of a thermocouple, which measures temperature, into the nest during the 60-day incubation period. Nest temperatures, it turns out, largely determine the sex of hatchlings. Warmer temperatures mean more females, colder temperatures more males. The temperature at which an equal proportion of the two sexes results reportedly lies between 84 and 86 degrees F. Therefore, knowing the nest temperature on Playa Grande and other beaches (which may vary slightly) is crucial to conservation efforts, which often include relocating nests that are prone to egg-poaching or seawater erosion.



One-watt transmitters strapped to adult leatherbacks (near right) send signals to satellites that track their long-distance migrations. To solve the mystery of where baby turtles go when they head out on the high seas (far right), even smaller transmitters must be developed.

One of the most tantalizing mysteries surrounding the leatherback is how it manages to survive in icy waters. Leatherbacks have been caught in 44 degrees F waters with internal body temperatures of over 77 degrees F. Some biologists have suggested they must have high metabolisms, like mammals or birds. But biologists Frank Paladino and James Spotila believe otherwise.

To analyze the turtle's resting metabolism, the two researchers placed sealed masks over the heads of nesting leatherbacks and collected their respiratory gases in large meteorological balloons. They later analyzed the gases for total volume and percentages of oxygen and carbon dioxide to develop an estimate of the turtle's resting metabolic rate—the amount of oxygen it burns per kilogram of body weight—after sitting immobile on shore for two hours. They

PHOTOS: ANAIKA DAYTON & SCOTT A. ECKERT

found that leatherbacks have a metabolism less than half that of a similar-sized mammal, such as a cow.

Paladino and Spotila theorize that leatherbacks are relying on a unique metabolic system they have termed *gigantothermy*. Gigantotherms—which may have included the dinosaurs, they say—have large body sizes and low metabolisms, and they use peripheral tissues (in the case of leatherbacks, their blubbery skin) as insulation. In leatherbacks, for instance, arteries and veins lie side by side, so that heated blood pumped out from the heart can warm chilled blood coming in from the extremities. This helps to keep the turtle's core body temperature high even in waters that would kill a human in minutes.

TRAILING THE TRUNKBACK

The most exciting insights biologists have gained into the lives of leatherbacks have come from data-gathering devices that unsuspecting females have carried with them into the deep sea. "We've always been accused of studying animals in a maternity ward," laughs Eckert, referring to working with females on and near nesting beaches. "Now we can step back and find out what they spend the other 99.9 percent of their lives doing."

Some of the earliest clues into leatherback behavior at sea, for instance, came from microprocessor-controlled time-depth recorders (TDRs). Attached to the animals' shells, these instruments, which biologists initially designed for studies of other great divers such as seals and penguins, record dive depth and duration, ascent and descent rates, and surface times. Eckert and his wife Karen, who is also a leading leatherback researcher, first shed light on the turtle's diving skills using TDRs on nesters departing Sandy Point, St. Croix. The females, they found, dove almost continuously, day and night, averaging ten minutes a dive and five dives an hour. They also dove more deeply during the day, often to profound depths. One turtle swam down 3,330 feet before the TDR stopped recording. While that dive remains the deepest on record, Eckert thinks leatherbacks routinely dive far deeper. After analyzing hundreds of dives, the husband-and-wife team believes the turtles are following the so-called deep scattering layer, a horizontal zone rich in jellyfish that rise to the surface at night to feed on phytoplankton but retreat during the light of day to depths below 1,800 feet, where the illumination is but 1 percent of that at the surface.



Biotelemetry, a means to remotely detect and measure movements and other conditions of wildlife fitted with electronic telemetry devices, has also helped clarify leatherback behavior on the high seas. To learn more about what Playa Grande females do in the days or weeks between nesting events, Paladino and his colleagues fitted individuals with radio and sonic transmitters and trailed them in boats as they left the beach. The radio transmitters allowed the scientists to monitor the surface activity and location of turtles up to 10 miles away. The sonic transmitters, whose sound waves travel readily through water, enabled them to record dives to depths of 1,500 feet and more.

Through this work, Paladino and his colleagues discovered, among other findings, that females awaiting another chance to nest spend their time diving and feeding at relatively shallow depths within about 40 miles of Playa Grande. At the end of a day of study, the researchers simply dove into the water to retrieve their instruments when the turtles surfaced.

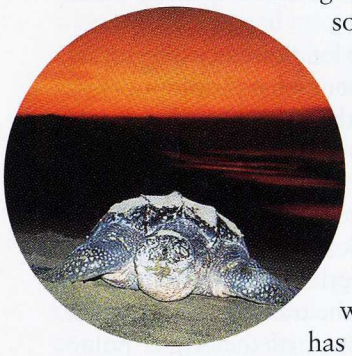
For turtles heading off on their long-distance migrations, the biologists needed equipment that could operate remotely. Satellite telemetry was the answer because tracking turtles this way, Eckert points out, means that "you don't need to chase them around." In June 1995, he outfitted three leatherbacks on a beach in Trinidad with one-watt satellite transmitters, each bearing an onboard microprocessor that recorded dive depths and durations. Each time a turtle surfaced, the transmitter looked for one or both of the Argos polar-orbiting weather satellites, each of which passes over the equator about four times a day. When a link was made, the transmitter sent a code identifying the turtle as well as a stream of data. The satellite, in turn, used a triangulation function to determine where on the planet the signal was coming from. If the turtle remained on the surface long enough, then the satellite got a solid fix on its location, often to within 500 feet, Eckert says. The satellite relayed the information to a ground-based receiving station, which forwarded the data by email once a day to Eckert's office computer.

For the first time, scientists were able to get a detailed look at where leatherbacks go on their ocean-spanning migrations. One of Eckert's transmitters failed after three months, but the other two each lasted for more than a year. (Eckert designed them to give out after about 40,000 transmissions, and for the harness that carried them to fall off the turtle after about a year.) In that time, the two turtles traveled more than 10,000 miles each. After leaving Trinidad, one headed north into subarctic waters, where it lingered for two months before heading south to the Canary Islands and onto to Africa. The other swam east, veering north about 1,000 miles west of Mauritania. It wound up in the

Bay of Biscay off France, then turned south, eventually approaching close to the African coast.

In the meantime, Eckert has been trying to improve his telemetric techniques. He recently outfitted nine leatherbacks on the Pacific coast of Mexico with improved transmitters designed to last for 250,000 transmissions over as long as 4 years. And he is now working on a transmitter that will use the Global Positioning System (GPS) to follow his turtles. "The beauty of a GPS location is that it's very easy to get," he says. Typically leatherbacks stay on the surface for only a few minutes, but the transmitters on his Trinidad subjects needed the turtles to be on the surface for at least five minutes to obtain a satellite fix. The GPS unit needs less than 20 seconds. Further, during that time Eckert will be able to communicate with the transmitter. "You can reprogram it, such as tell it to turn itself off for a month if you're getting data from areas you don't want," he says.

While satellite-tracking eight leatherbacks on the Pacific side, Paladino and his colleagues made an interesting discovery. Turtles leaving Playa Grande can depart anywhere along an arc of about 160 degrees. Yet all eight turtles in the study headed southwest along the subterranean Cocos Ridge to the Galapagos Islands; four continued past the Galapagos into deeper Pacific waters. The biologists believe the turtles are migrating along distinct ocean corridors, which they conservatively estimate to be about 300 miles wide. At Playa Grande, Paladino has begun to investigate how the turtles sense such routes. Normally newborn leatherbacks exiting the beach invariably head straight out to sea. But when Paladino temporarily glued magnetized needles with about twice the strength of the planet's magnetic field to the turtles' heads, they began wandering aimlessly. "When you disrupt their ability to sense the earth's magnetic field," he says, "they seem to go in a random pattern."



Eckert considers the jury still out on whether specific pathways exist; his three Trinidad turtles, for instance, headed in three different directions. If such corridors do exist, however, they could go a long way to help protect the species on the high seas, Paladino says, for authorities can know when and where to restrict the long-line fishing operations that drown thousands of leatherbacks each year. Indeed, the new knowledge about leatherback behavior that biologists are now collecting is giving them renewed hope that the species can be pulled back from the brink of extinction. "Using satellite telemetry and other technologies that allow us to understand leatherback movements and habitats," says Eckert, "gives us the tools we need to respond, for instance, to fishermen who say 'We want to build a new fishery out here.' We can say, 'Fine, but here's what you need to avoid.'"

PRESERVING THE SPECIES

After taking the blood sample, we release the leatherback from her temporary bondage and watch as she hauls herself toward the breaking surf. The high tide, which she had relied on to carry her as far up the beach as possible, has begun to go out, making her journey more taxing than on the way in. She breathes hard, and the bulbous flesh on her neck and shoulders glows crimson from the exertion. But she presses on, leaving a track in the sand five feet wide. Before long, the first frothy waves begin splashing over her broad back. A few minutes later, she regains buoyancy and instantly vanishes into the sea.

More research will be needed to determine whether this leatherback then swam down a sea-turtle highway to her feeding grounds—and to solve an ocean of other mysteries about leatherbacks. Some questions, such as where baby turtles go when they disappear into the waves, may have to await breakthroughs in available technologies, such as miniaturized satellite transmitters perhaps, or even new technologies altogether. "When I think about trying to figure out where those hatchlings are going out there, it makes me blanch," Eckert says. But it hardly deters him. "We have to get a better understanding of where leatherbacks go, what they're doing out there, and what habitats they need to survive, or we're wasting all our efforts everywhere else," he adds, referring to attempts to safeguard nesting beaches. "That's my crusade of perhaps the next 50 years."

Another crusade of Eckert's is informing the general public about leatherbacks and their plight. "It's your long-term insurance," he notes. One of the best ways to educate people, he says, is with yet another burgeoning technology—the Internet. There are now a number of popular sea-turtle-oriented Web pages, and some researchers, including Paladino's colleague Edward Standora of Buffalo State College in Buffalo, N.Y., have begun to put their satellite tracks out over the net, so schoolchildren can watch the turtles' progress. "The Internet is an inexpensive way to distribute information to a very wide readership," Eckert says, "and any time you do that you're benefiting conservation of the species."

Meanwhile, until wider scientific understanding of leatherbacks exists, researchers agree that the most promising way of preserving the species remains protecting its nesting grounds. Toward that end, there is good news at Playa Grande. In July 1995, the Costa Rican government declared Playa Grande and two neighboring nesting beaches a national park, Parque Marino Las Baulas, or "Leatherback Turtle Marine Park." Beyond a strong national conservation ethic, the Costa Rican authorities granted protection largely based on Paladino's and Spotila's cutting-edge research. ■

PHOTO: SCOTT A. ECKERT

FORUM
BY PHIL AGRE

The Next Internet Hero

EVERY new technology is accompanied by a grand narrative. The Internet's narratives have focused on heroes: people who are leading the transition to a more information-intensive society. The Internet has produced two generations of hero figures. Now it's time for a third.

The first hero was the good hacker. The Internet originated in a special setting — the community funded by the Advanced Research Projects Agency (ARPA). These earliest hackers were establishment revolutionaries. Their guiding narrative was that information technology and human beings are symbiotic elements of a larger system. They owned the biggest computers and they defined the technologies that became the Internet.

The next Internet hero was the rebel hacker. This second generation viewed hacking as something that happened outside of established institutions. Electronic mail, for example, symbolized and sometimes aided resistance to hierarchy. Rebel hackers include the "cypherpunks," who resist authority by propagating robust encryption software. But rebel hackers can be found in practically any organization; they were the folks who spent their evenings and weekends creating the first million or so Web pages during the early-to-mid 1990s. More social movement than business practice, these Web projects were rarely integrated into organizational procedures or strategies.

The rebel hacker is guided by the notion of cyberspace, a digital ether that transcends the obsolete constraints of the physical world. This is a religious idea, and it inherits a long millenarian tradition. It promises to level hierarchies, erase borders, confound the powers of the earth, and institute a perpetual utopia of peace and plenty for all. A belief in cyberspace is the twentieth century's last revolutionary ideology.

The grand narrative of cyberspace, however, no longer tells us what we need to know. The rebel hackers derived their revolutionary edge from the continuing rapid growth in microprocessor power, telecommunications bandwidth, and data storage capacity. Dramatic improvements in information technology, they said, would surely turn society inside out. But this argument is misleading. We can indeed be confident that the basic building blocks of computers and networks will continue to improve. But we cannot predict what will be built from them—the architecture of the many-layered information infrastructure that is rapidly emerging around the world.

The technologically adventurous folk who planted the seeds for the Web have done their job. Now it's time for a new breed—the public hacker—to take over.



The questions are endless: Will online commerce systems support anonymous payment, or will they keep complete records of our transactions? Will our electronic communications systems let users screen out unwanted messages, or will we drown in mass mailings? Will educational systems support new kinds of learning, or merely introduce new forms of rote drill? Will the Internet continue to embody the scientific community's values of open information, or will it converge with the business models of broadcast media? The answers are not dictated by the basic workings of the machinery. They are matters not for prediction but for choice. The Internet is becoming integrated with institutions, influencing them and being influenced in turn. Society needs institutions, after all, and information technology provides us with a tremendous opportunity to redesign our institutions in ways that express the values of a democratic society. This is not a job for the rebel hacker, who is sworn simply to resist the bad institutions of yore.

That's why we need a new kind of Internet hero: the public hacker. Whereas the good hacker and the rebel hacker changed the world by changing technology, the public hacker builds bridges between the esoteric world of technical work and the bigger, messier world in which values are argued and chosen. The public hacker is bilingual, translating between technical issues and legal issues, between the dynamics of systems and the dynamics of communities, between technological visions and social visions.

The public hacker still invents technologies when they're necessary, propagates them when they're useful, and defends them when they deserve it. But this new hero's imagination is not entirely driven by the machinery. Some examples: Mitchell Kapor, co-founder of the Electronic Frontier Foundation, helped catalyze a remarkably broad-based public discussion of the social values at stake as we create the information infrastructure. Peter Neumann edits an Internet forum, the Risks Digest, that has sensitized innumerable computer people to the things that go wrong with computer systems in real institutional settings. And Pamela Samuelson brings technical and legal analysis together in the public sphere, helping policymakers tackle the intellectual property issues that arise in digital media.

If these people don't seem like traditional heroes, perhaps we need a new conception of heroism. Revolutionary heroes changed the world in a unilateral way. Now we need heroes who can help us imagine our options. ■

PHIL AGRE is professor of communications at the University of California at San Diego and editor of an Internet mailing list devoted to the social aspects of computer technology. His most recent book is Computation and Human Experience *(Cambridge University Press). He can be reached through his Web site, http://communication.ucsd.edu/pagre/.*

PHOTO: TIM RUE

Look Out for the Luddite Label

Society suffers when skeptics about the juggernaut of technological change are pushed to the policy-making sidelines.



LANGDON WINNER

"I'M no Luddite, but...." we often hear people give this apology as they begin even the most tepid criticism about some technology or another. Evidently, it's important to let everybody know that you still affirm the overall beneficence of technological progress. How astonishing, then, to read in the *Wall Street Journal* and other recent press reports that a movement of "Neo-Luddites" is taking shape in the United States.

The original Luddites were displaced workers in early nineteenth-century England who resisted the destruction of their traditional, crafts economy by mechanized industrial production. In an era when labor organizing was illegal, the followers of the mythical "Ned Ludd" smashed textile machines as a protest against a system whose rise spelled their eventual doom. In the end, the British army brutally crushed the rioters.

Those who adopt the term Luddite today (or have it thrust upon them by others) turn out to be a diverse group of writers and social activists—Stephanie Mills, Jerry Mander, Wendell Berry, Chellis Glendinning, Kirkpatrick Sale, and Andrew Kimbrell, among others—whose views include a marked skepticism about what mainstream thinking considers economic and technical "advance." They argue that our technology-driven world is moving too fast in the wrong direction.

Among the beliefs they share are the following:

- Simple, conventional tools are often superior to the complex, high-tech instruments that replace them.
- Technical change ought to be guided by principles of social justice, ecological harmony, and personal dignity rather than the untrammeled pursuit of efficiency and profit.
- It is better to derive energy from renewable resources than from burning oil and coal.
- Methods of organic farming are superior to those of chemical-intensive agriculture.
- Local and regional economies are more sustainable than ones geared to global production and trade.
- The pursuit of a well-balanced life is not compatible with the speed and intensity of activity that today's digital electronics demand.

Neo-Luddite philosophers do not oppose technology per se; rather, they present a collection of arguments about what good technologies would look like and how to cultivate the wisdom needed to choose them. In fact, many enthusiastic techno-skeptics in this camp are deeply involved with highly sophisticated—though not necessarily modern—technical devices. Thus the writings of philosopher/novelist Wendell Berry describe in loving detail what the implements and methods of traditional agriculture mean for the soil, plants, and communities that use them. Eco-anarchist filmmaker Godfrey Reggio employs state-of-the-art tools of cinematography in movies that starkly depict the dangers of today's global production system. Do these choices make Berry or Reggio "anti-technology"? Only zealots for technologies of a different brand would make that claim.

The ultimate purpose of labeling some approaches to technical practice as anti-technology or Luddism is not difficult to discern. Applying the decals of opprobrium—romantic, unrealistic, negative—to dissenters effectively excludes them from policy debates. When those who have serious reservations about the latest high-tech development are marginalized and stigmatized, the juggernaut of ill-considered change can proceed unimpeded.

President Clinton's National Information Infrastructure Advisory Council, for example, recently assembled a panel of luminaries from electronics and communications firms, the entertainment industry, and education to examine prospects for computerizing the nation's schools. But virtually all of the panelists convened were known in advance to be gung-ho for wired education. Not surprisingly, reports on the deliberations of the council stressed the unanimity of panelists' views; apparently few members expressed any fundamental doubts about the wisdom of the project they were considering.

This way of stacking the policy deck is lamentable. Many technologically savvy experts in education now fear that saturation of schools with electronic gadgets is doing more harm than good. But none of the prominent skeptics on this matter, such as New York University's Neil Postman and Stanford's Larry Cuban, were invited to join Clinton's advisory group. Thus, the planning of a grand strategy for American education proceeded smoothly, without any sour notes—and without meaningful debate.

In a climate like this, is it any wonder that people feel compelled to beg forgiveness for occasional lapses into technology criticism? When mere boosterism is mistaken for serious advice, people of a different mind are dismissed as Neo-Luddites. Labels of this sort speed the onslaught of thoughtless innovation, crippling serious debate about the technological alternatives that confront us. ■

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PHOTO: L. BARRY HETHERINGTON

FORUM

BY TACHI KIUCHI

What I Learned in the Rainforest



To grow and thrive, businesses should heed a few simple principles drawn from the globe's most diverse ecosystem.

I have learned my most important lessons about business in the forest.

My first lesson came 37 years ago, days after I graduated from the University of British Columbia. I was asleep. This was unfortunate, because I was driving through the Canadian Rockies at the time, headed toward a cliff. After waking up two days later in the hospital, with my jaws wired shut, I had plenty of time to reflect upon this incident.

Since then, I have come to believe that the global business community is driving quickly toward a cliff, with its eyes closed, and will soon suffer a similar fate. If we opened our eyes, we would see that 600 million of the earth's inhabitants in Europe, Japan, and the United States enjoy the material benefits of industrialism and that 2.5 billion more from China, India, and the former Soviet republics will join us. After them, the final 3 billion deserve the same. Yet to accomplish that goal today, we would need the resources of three planets. But we have only one. Thus our businesses need to begin creating affluence without effluence.

I am often told the needs of business and environment conflict—that the highest mission of a corporation is to maximize profits. But in the long term, there is no incompatibility. For example, a large market will arise for photovoltaic solar cells, especially in the developing world. Mitsubishi's work on such devices serves the company but also the global environment. Ultimately, profit is just money—a medium of exchange. You always trade it for something else. We don't run our business to earn profits. We earn profits to run our business.

And imagine how creative, how productive, how ecologically benign our businesses could be if we ran them according to the design principles of the rainforest. With thin soil, few nutrients, and almost no resources, rainforests could never qualify for a loan. Yet rain-

ILLUSTRATION: SUSAN LEVAN

"With thin soil, few nutrients, and almost no resources, rainforests could never qualify for a loan. Yet rainforests are more productive than any business in the world."

—TACHI KIUCHI



forests are more productive than any business in the world, home to millions of species of plants and animals, so perfectly mixed that they sustain one another and evolve into ever more complex forms. These environments excel by adapting to what they don't have.

Emulating the rainforest means following basic principles of ecology:

■ Get feedback. In the rainforest, feedback leads to Darwinian evolution of a complex array of diverse organisms.

Individual humans have excellent feedback systems—our eyes, our ears, our minds. But in our companies and communities, our collective feedback systems are not so well developed. My priority at Mitsubishi Electric is to create the world's best corporate feedback system so that we know the costs and benefits of every product—including the social and environmental needs we can help fulfill—better than any other electronics company. In business, feedback indicates the potential for market demand. If consumers favor products and companies that avoid doing harm to the environment, then an alert company will profit by making such products. For example, Mitsubishi developed one of the first refrigerators that did not use chlorofluorocarbons—the chemical responsible for eating away the ozone layer—and is now a leader in that market.

■ Adapt and change. It is not enough to see the cliff—the opportunities. We must turn. We all know that what gets measured gets done. Thus starting next year, Mitsubishi Electric will track not only quarterly profits but also our facilities' level of polluting emissions and how efficiently they use resources. We will also create incentives that reward people when they take steps to reduce damage to the environment. Such rewards might go, for example, to those at the company who develop a television picture tube that does not contain lead and that therefore can be disposed of in a landfill without poisoning the earth.

■ Fit a niche. In the rainforest, conformity causes extinction. If two organisms have the same niche, only one survives. The other either adapts or dies. It is the same in many high-tech businesses. If two companies make exactly the same leading-edge product, only one survives. But in the rainforest, there are many winners. The same can be true in our economy. The question is not who is most fit, but where we best fit. If we fit—solve a social problem, fulfill a social need—we will survive and excel.

But what are most companies doing today? They are downsizing radically, desperately seeking the lowest cost. It is smarter to differentiate—to create distinctive products and fill unique niches. Mitsubishi learned this the hard way. We found we could not compete by always selling the cheapest TVs, stereos, and appliances. Rather than kill or be killed by our competitors, we must sidestep them by creating unique products that appeal to particular consumers.

■ Cooperate. The rainforest's vitality and diversity stem from the fact that all the organisms together create a more efficient whole. Today, as companies grow different, we need each other to fill our gaps. Mitsubishi, for example, no longer expands simply by buying companies as subsidiaries. We profit more from cooperative joint ventures in which our partners retain their independence, specialty, and core competence. In one example of such a venture, Mitsubishi is working with an independent appliance dealer in Wisconsin to create a new company, Air Tech, to market a passive air exchanger and cooler that both lowers energy costs and helps prevent "sick building" syndrome. The product grew from collaboration between Mitsubishi Electric, which knew the technologies, and the dealer, who grasped the potential market for such a system among architects and builders. These cooperative relationships are now as vital to our future as are our products.

In Japan, we have two terms that help us understand why: omote and ura. Omote is the surface or front of an object—the external reality. Ura is the underlying reality. As business people, we have been looking at the rainforest all wrong. What is valuable about the rainforest is not omote—the trees, which we can take out. The real value of the forest lies in its ura—the design and the relationships among species. And the highest mission of business is to help fully develop the human ecosystem, sustainably like the rainforest, in all our diversity and complexity.■

TACHI KIUCHI is managing director of Mitsubishi Electric Corp. and chair of the Future 500—a network of companies dedicated to sustainable industry based in Sacramento.

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Reviews

BOOKS

LEARNING FROM VENUS

Venus Revealed: A New Look Below the Clouds of Our Mysterious Twin Planet
by David Harry Grinspoon
Addison-Wesley Publishing Co., Inc., $27.50

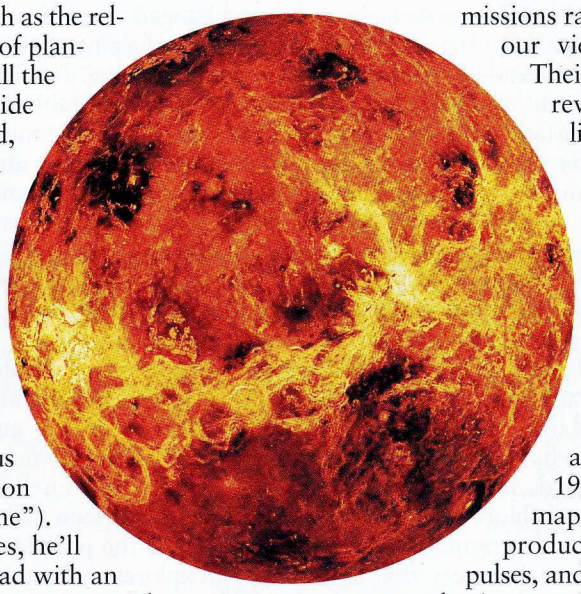
BY MARK DWORTZAN

In the 1960s, intent on demonstrating the superiority of our military-industrial complex to the Soviet Union, we funded the space program to reach the moon. In the 1970s and 1980s, we began to justify space expenditures by touting Teflon pans, super metal alloys, and miniaturized robotics. Now a new rationale for planetary exploration has emerged—environmentalism. The more we know about other worlds, say space enthusiasts, the better we can tackle the environmental dilemmas that beset our own planet.

So argues planetary scientist David Harry Grinspoon of the University of Colorado at Boulder, in *Venus Revealed: A New Look Below the Clouds of Our Mysterious Twin Planet,* the first book to explain the findings of the Magellan mission. Expertly guiding the reader beneath the clouds that have long hidden Venus from earthbound eyes, Grinspoon celebrates Magellan and other spacecraft voyages that have increased our understanding of our sister planet's geology, climate, and atmosphere. At the same time, he acknowledges that these insights may not play well with a taxpaying public facing declining schools, disintegrating inner cities, overpopulation, and many other social ills. So throughout the book, Grinspoon emphasizes how missions like Magellan may lead to practical solutions to problems here on earth, such as ozone depletion, global warming, and acid rain.

What's striking about *Venus Revealed,* besides some captivating Magellan photos of the Venusian landscape, is the author's informal style. It immediately comes across in the introduction, where he describes an exhilarating drive up California's Pacific Coast Highway to catch views of Voyager 2's Neptune encounter at the Jet Propulsion Laboratory in 1989. This journey sets the tone for the rest of the book, which Grinspoon delivers like a smart, irreverent travel companion on a long-awaited road trip.

And there's no excuse to drift off. If Grinspoon thinks you may be losing it during a discussion of a complex topic such as the relative motion of planets, he will pull the car to the side of the road, and bring you up to speed with an explanation section entitled "Who Cares?" or a sports analogy (on the solar system track, "Venus is a runner on the inside lane"). At other times, he'll lighten the load with an amusing footnote or quirky subtitle.



Taking the reader on a fascinating historical tour of Venus as seen from the imagination, telescopes, and spacecraft, the author gradually brings the planet into focus. Before the invention of the telescope, stargazers noticed how Venus stood out in the night sky. It was not only the brightest object, but also a quixotic companion to the sun, putting in rotating nine-month appearances as evening or morning star. The eye-catching planet inspired reverence in many ancient cultures, becoming a symbol of birth, death, and resurrection, a beacon of fertility (with its appearances matching the human gestation period), and a goddess of love.

Starting in the 1600s, astronomers viewed Venus through the telescope, initially discovering its moonlike phases, and later detecting an atmosphere, leading to speculation that Venus was a "swamp world," with oceans, vegetation, and rain. But swathed in a global blanket of clouds, Venus refused to reveal its secrets through optical telescopes. To penetrate the cloud cover, twentieth century scientists turned to other instruments, such as ultraviolet detectors and radar.

From 1962 to 1994, an armada of 24 Soviet and American spacecraft missions radically altered our view of Venus. Their observations revealed a dimly lit planet largely devoid of water, with a 900 degrees Fahrenheit surface temperature, a 97 percent carbon dioxide atmosphere, and sulfuric acid clouds. By 1990, topographic maps, which were produced by radar pulses, and ground-based radar images yielded a fuzzy, incomplete picture of the surface.

Then came Magellan. Launched in 1989 and operating until 1994, Magellan "more than all the other spacecraft combined," transformed Venus into a place, writes Grinspoon. The orbiter, carrying an onboard radio telescope that could resolve surface features as small as a football field, generated the radar equivalent of an *Above Venus* photo book.

According to an effusive Grinspoon, "It was like finally, after decades of squinting, getting the right prescription for your glasses and seeing the world in focus." What Magellan "saw" was a well-preserved assortment of volcanic features (including pancake domes, meandering "river beds" apparently

PHOTO: NASA

carved out by molten fluid, and basalt plains), tectonic scars (folds, fractures, and faults), prominent highlands, and highly reflective mountaintops. The surface, averaging only 500-600 million years old ("What's a hundred million years among friends?" quips Grinspoon in a footnote), displayed only about 900 craters, prompting scientific speculation that a catastrophic event induced a "planetary makeover" about half a billion years ago.

In Grinspoon's view, the findings of Magellan and other spacecraft have shown Venus to be our planet's "fraternal twin." While differing severely in many characteristics, Venus closely matches earth in others—size, mass, and distance from the sun, a geologically active and volcanic surface and an evolving atmosphere with complex chemical cycles.

Indeed, Venus's atmosphere and clouds display processes with strong analogies to environmental problems on earth, compelling Grinspoon to include a section entitled "A Case of Venus Envy?" The atmosphere contains greenhouse gases (principally carbon dioxide), which trap heat beneath the clouds, globally warming the planet's surface in a process similar to what happens on earth. Atop Venus's clouds, ultraviolet light rips apart fluorine and chlorine compounds, yielding chemical compounds that deplete ozone—a discovery that contributed to scientists' investigations of a similar phenomenon on our planet. And Venus's sulfur dioxide clouds produce acid rain, a form of precipitation that continues to threaten earth's lakes and forests.

These similarities—especially the greenhouse effect—have led many scientists to support missions to Venus, touting our sister planet as a model of what earth might become unless we significantly reduce our fossil-fuel consumption. But Grinspoon convincingly argues that "the lesson we can learn from the Venusian climate is not 'Don't let this happen to your planet,' but rather 'Here is another nearby planet with a complex, evolving climate system; study it and you will achieve a more mature, less provincial understanding of planetary climate.' And that *could* save our hides."

While Grinspoon clearly supports robotic space exploration for curiosity's sake ("Beauty and mystery are reason enough to explore"), and argues that the United States could fly five advanced geoscience and climatology missions to Venus for the $1 billion cost of a Stealth bomber, he stresses that such projects are "ultimately vital to maintaining and enhancing the planetary perspective that may save us from ourselves." Grinspoon deftly shores up this argument by pointing out how Apollo photos of earth "forever changed the self-image of earth's inhabitants, helping to awaken our latent planetary identity." The first indication of this was the inaugural Earth Day (1970). Moreover, the Apollo mission led scientists to sound the alarm about the potential harm of chemical reactions associated with CFCs to earth's ozone layer. After several scientific papers, research programs, and global conferences, international agreements were forged to phase out CFC use.

Despite these success stories, funding space exploration remains a gamble, since there's never a guarantee that learning about the unknown will pay off in more than intellectual terms. Although Grinspoon makes an interesting case for the practical potential of Venus exploration in addressing earth's environmental problems, he fails to adequately explore the relative cost-effectiveness of more direct approaches, such as targeted economic and technical programs. A case in point is NASA's upcoming Mission to Planet Earth project, which aims to systematically study our planet with remote-sensing satellites.

In a final chapter about the possibility of life on Venus, Grinspoon's literary journey begins to veer onto dirt roads. He speculates on prospects for finding or introducing life on Venus and the significant challenges of manned planetary missions. While these side trips are intriguing, they ultimately distract the reader from the book's central theme—the excitement and practical value of planetary exploration.

On the whole, however, Grinspoon's joyride to Venus and back is truly consciousness-expanding, transforming our nearest planetary neighbor into much more than a bright dot in the sky. If you read *Venus Revealed* inside, you may find it difficult to suppress the urge to lay it down, go outside, and catch a glimpse of our spellbinding celestial twin.■

MARK DWORTZAN was a mission design engineer from 1984 to 1988 at the Jet Propulsion Laboratory in Pasadena, Calif. He is now completing Boston University's Graduate Program in Science Journalism.

BOOKS

RECONCILING THE VISIONARY WITH THE INVENTOR

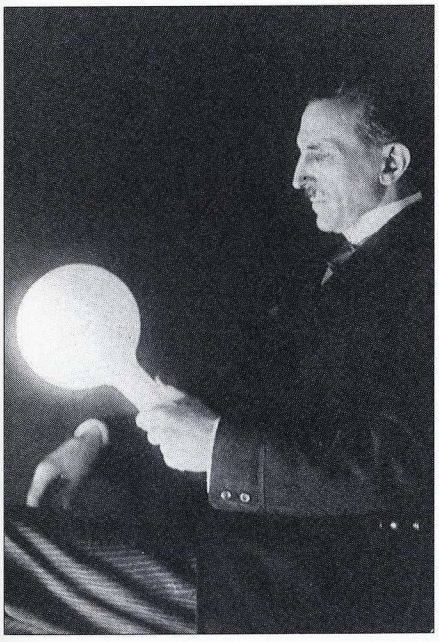
Wizard: The Life and Times of Nikola Tesla
by Marc J. Seifer
Birch Lane Press, $32

BY LISA GITELMAN

NIKOLA Tesla (1856-1943) emerged from a Serbian family in a remote Croatian village to become a world-famous inventor at the age of 32, when he sold his patent rights to a system of alternating-current (AC) dynamos, transformers, and motors to George Westinghouse. By developing a motor that converted AC into motive power, Tesla laid the groundwork for today's electrical geography. Before his inventions, electric power lingered as an isolated, local utility, available only at great expense through Thomas Edison's direct-current (DC) system. The deal between Tesla and Westinghouse led to a showdown between the DC approach and the AC system—the latter of which eventually won out.

The tale of Tesla's humble beginnings,

ingenuity, and early success would appear sufficient to garner him everlasting renown. But despite Tesla's impact on electricity, history does not regard him as highly as many of his inventive contemporaries. As Marc J. Seifer, the author of *Wizard: The Life and Times of Nikola Tesla* shows, Tesla's later claims of wizardry and his outlandish predictions about technology's future transformed him into a laughable figure during his lifetime. At times inept at handling his own celebrity or



courting the press, Tesla waited too long to claim precedent-setting accomplishments in transmitting radio signals over great distances, yet in 1899 he announced publicly that his Colorado Springs laboratory had received signals from Mars. Today, however, the author, among others, champions Tesla as a neglected genius and the father of such later marvels as cellular phones, digital communications, and pixels.

The combination of hoarded secrets and flamboyant pronouncements made Tesla hard to trust. Although he was also a pioneer in fluorescent lighting and wireless communication, Tesla, unlike Edison or Guglielmo Marconi, failed to translate public attention into the sort of financial support that might lead to an enduring corporate legacy. Despite his sheer brilliance, he had little of the know-how required for success and ultimately failed as an entrepreneur.

As Seifer shows in great detail, Tesla's quirks further damaged his reputation. The inventor who had learned to handle high voltages apparently lived in abject terror of germs. He followed his own peculiar dietary rules; in his later years, Tesla lived only on milk, bread, and vegetable juices. And he imagined enemies among his influential contemporaries, whether for legitimate or exaggerated slights, withdrawing in bitterness from Edison and physicists Michael Pupin and Heinrich Hertz, as well as from many in the Westinghouse and General Electric companies.

Tesla lived out the last of his days alone, feeding the pigeons in New York City. When he died, the only American to believe in one of his favorite inventions, a supposed "death ray," was J. Edgar Hoover, who appears to have ordered the collection of Tesla's papers and effects. The FBI eventually returned them to Serbia, where they now reside in a Belgrade museum devoted to Tesla's memory.

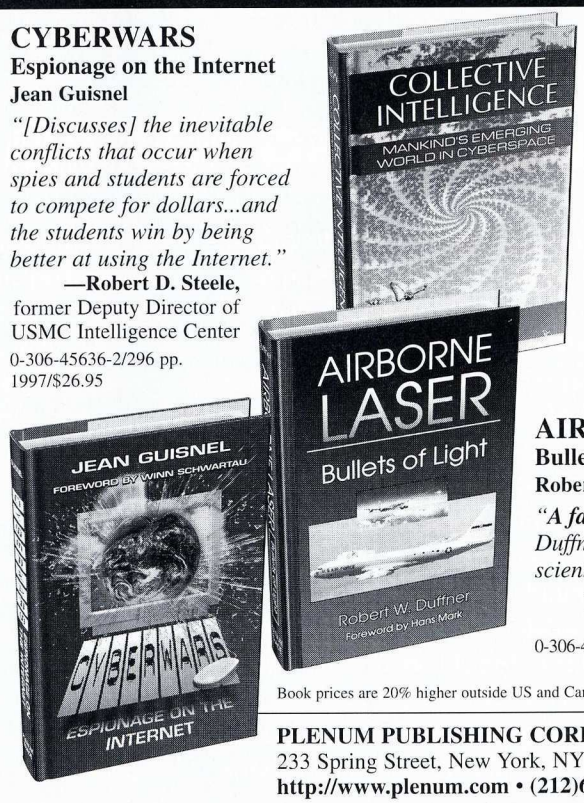
Overall, Tesla's story is complicated and tests our definition of science and technology as stemming from participants whose articles can be cited and whose creations can be linked directly to their inventor. Where does someone like Tesla fit in? For all his inventions and dreams, can we believe Seifer's claim that Tesla's numerous experiments foreshadowed Wilhelm Röentgen's discovery of x-rays or Albert Einstein's exploration of quantum physics? Could Tesla have envisioned facsimile machines, video cameras, digital recording, artificial intelligence, and

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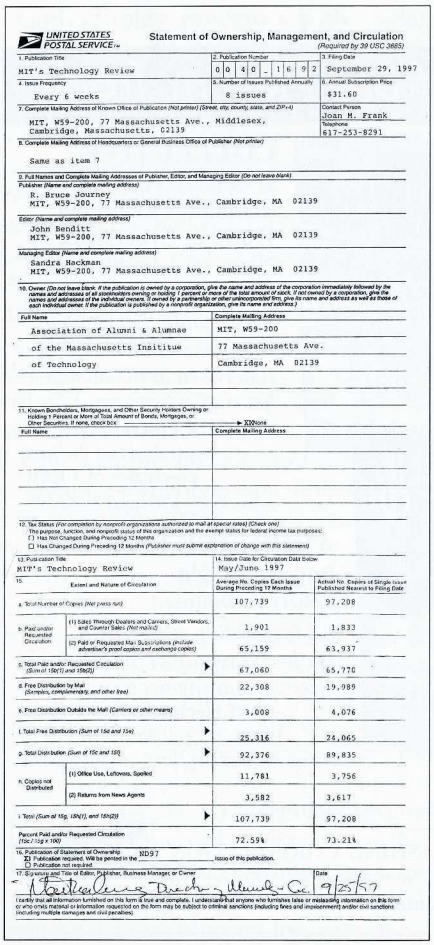
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robotics? Answers to some of these questions may be affirmative if we are willing, for instance, to allow that Leonardo da Vinci invented the helicopter, when he drew a fanciful, vertical-lift contraption in one of his Codices.

Unfortunately for those unfamiliar with Tesla's work, the author, who teaches psychology, may not have the expertise to understand Tesla's contributions fully. In fact, since Seifer's technical explanations can be puzzling, serious readers may want to read *The Complete Patents of Nikola Tesla* (Barnes & Noble Books, 1994), a compendium of the inventor's patented works, to help them determine their view of the inventor's rightful place in history.■

LISA GITELMAN teaches American studies at Rutgers University, where she is also an editor with the Thomas A. Edison Papers Project.



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CONTINUED FROM PAGE 8

streets pedestrian friendly). Social change happens when communities discover that they possess the tools to stand up to the pave-at-any-cost attitude of many highway officials and when people realize that they shouldn't have to drive to the market, the library, and the softball field.

ROBERT H. RUSSELL
Attorney
Conservation Law Foundation
Boston, Mass.

Growing up in one of Boston's neighborhoods, I learned firsthand what an asset it is to live where my family and I could walk to buy food, clothing, and other items, and to get to school, the playground, the local ballfield, the bowling alley, and the movie theatre. My mother also walked to work and was nearby if we needed her, and my father was a short streetcar ride away. My parents never chauffeured us anywhere. How many beleaguered parents can say that today?

As an adult, I purposely moved to Hyde Park, another Boston neighborhood. Every day, I walk five minutes to the commuter rail and take a short ride to my job. I've made friends with people I never would have met if I didn't ride the train. For those of us who don't have Jane Holtz Kay's courage to give up our cars, we can at least make such lifestyle changes so that we drive many fewer miles.

GLORIA GANNO
Hyde Park, Mass.

By avoiding car ownership, Jane Holtz Kay portrays a romantic notion of conservation. However, although she estimates that her car-free life saves her at least $6,000 annually, she never once tallies the costs of public transportation, time lost, and the shifting to others of expenses when she solicits rides. These factors may significantly lower her real savings.

As a resident of one of Boston's major North Shore suburbs, I would have to spend more than 10 minutes walking to public transportation. Commuting by cab would cost me $25 daily—a cost that would rise on days when I need to travel to multiple sites. If I gave up my car, I could look forward to less net income and more hours away from home. I don't think my wife would find that conservation idea romantic.

EDISON H. WONG
Danvers, Mass.

I am pleased that Jane Holtz Kay chooses to live without a car; I wish all urban residents would do the same. However, her article shows how misguided liberalism can work for some people but is completely impractical for most. I survived my four student years in Cambridge, Mass., quite nicely without a car, thanks to Boston's wonderful transportation system. But after graduating and transferring to a military base in Pensacola, Fla., where the nearest grocery store is a 45-minute ride away, I quickly purchased a full-size American-made pickup truck and, 100,000 miles later, couldn't be happier. I thoroughly enjoy my 35-mile round-trip commute, using the time to relax and collect my thoughts. And I regularly take long road trips to enjoy the beauty of the U.S. countryside.

In many areas of rural America, the nearest town, school, church, and grocery store are miles away. Cars are more than a luxury item in those areas; they are essential to the inhabitants' way of life.

CHRISTOPHER M. REIN
Norman, Okla.

CORRECTION

In "Brother, Can You Spare a Cyclotron?" (*TR August/September 1997*), Sidney Perkowitz stated that the MIT Wavelength Tables, which determine the characteristic light emitted by each element in gaseous form at high temperatures, found that mercury emits "a red glow." Actually, under those conditions, mercury emits an intense blue-white glow.

Continued on page 70

InSight



WASHING A MIRROR OF THE UNIVERSE

Cleaning this giant "eye" is anything but a pedestrian task. The job was the last one performed by Corning technicians in New York state before they shipped the mirror blank to Paris for grinding and polishing, in preparation for the eight-meter-diameter mirror's use in one of the world's largest telescopes.

The work is part of the international $176 million Gemini Project, which plans to finish constructing two identical telescopes on mountaintops in the Northern and Southern hemispheres—Mauna Kea, Hawaii, and Cerro Pachon, Chile—by 1998 and 2000, respectively. Designed to detect infrared wavelengths of light, a method that produces clear extraterrestrial images, the scopes will let researchers try to discover planetary systems and more distant stellar birthplaces and galaxies, says Matt Mountain, director of the Gemini Project. The latter work should enable astronomers to track the history of stars' and galaxies' formation.

In part, the telescopes will be the product of "superb mechanical engineering," Mountain says. Making the 22-ton mirror required producing and fusing 55 hexagons of glass that remain virtually constant in size during temperature changes. Technicians then reheated the giant blank to slump it to precise specifications before applying an acid-etch treatment to the underside that rounded off corners of microcracks and reduced the chance of their propogating. Now French technicians at REOSC Optique are shining the top surface so smoothly that were the mirror to stretch across the Atlantic Ocean, no blemish would protrude more than an inch from the surface. To clean the mirror, Gemini experts are considering using a carbon-dioxide gas that sprays on like snow to blast off contaminants weekly.

—*Laura van Dam*

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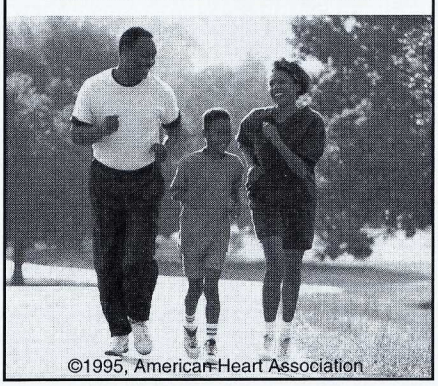
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ELECTRIFYING GARBAGE PICKUP

I enjoyed "Next Stop: The Electric Bus" (*TR May/June 1997*) by José Goldemberg and Hal Harvey, and agree that the first vehicles we consider converting to electricity should not necessarily be private cars. Besides buses, I think garbage trucks should also run on electric power. When they rumble past my home on Monday mornings, I consider their features: they don't go very far or very fast; they start and stop a lot; and they operate in residential areas, where the noise and exhaust are problems. The potential benefits from converting them to electric power are great and the public backlash against this type of electric vehicle would be minuscule.

JEAN-JOSEPH COTE
Boulder, Colo.

FORTIFYING THE HEART

I was surprised that Howard L. Lewis's "Penetrating the Riddle of Heart Attack" (*TR August/September 1997*) did not mention Kilmer McCully's research on heart disease, which was covered recently in the *New York Times Magazine* (August 10, 1997). The latter reported that McCully, who started his work in the 1960s, found that a high level of the amino acid homocysteine in the blood causes at least 10–15 percent of all heart disease cases. Nutrition apparently plays a role: a high amount of homocysteine has been linked to insufficient intake of folic acid and vitamins B-6 and B-12.



GERALD J. MANTELL
Allentown, Pa.

The author responds:

My original manuscript identified high levels of homocysteine as a risk. Although an editorial decision deleted that reference, heart disease clearly results from many risk factors working together over a period of time to cause damage to the blood vessels and organs, bringing on a heart attack.

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